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# LANDFILLING OF HAZARDOUS WASTES

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# LANDFILLING OF HAZARDOUS WASTES

by

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for the

Waste Management Branch
Environmental Protection Service
Environment Canada

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# CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations provided here form a summary of guidelines or alternative approaches proposed in the body of this report. The conclusions and recommendations are presented as a basis for discussion in the development of guidelines. The thrust of the report is to assist in ensuring that secure landfills are developed in a manner which minimizes risk to human health and the environment. As ground water contamination poses the greatest potential threat to human health and the environment, particular attention has been devoted to that area of concern.

They are presented in the sequence in which they are developed in the report and are cross-referenced to the appropriate section where more details can be found. As a general comment, it should be noted that numerical standards are relatively scarce, reflecting the site-and/or waste-specific dependency of many of the guideline areas. Included in this summary is a listing of those areas where further research and development is needed to resolve uncertainties in the current state-of-the-art associated with land disposal.

## a) Risk

- The assessment of risks should be undertaken in as precise and as explicit a manner as possible. Such an approach would involve: documenting the rationale for simplifying assumptions; acknowledging value judgements and areas of uncertainty; substantiating standards; and acknowledging the limits of technology, methods and procedures.

- A number of steps can be taken to reduce the uncertainty associated with hazardous waste landfills. Preference should, for example, be given to sites with simple environmental conditions. Technological, design and management components with proven reliability should be emphasized. The potential for synergestic effects should also be minimized.

  In addressing areas where there is a high degree of uncertainty, wide margins of error should be assumed and allowance should be made for as wide a range of outcomes as possible. As there will always remain some element of risk, contingency and emergency planning should receive particular attention.

- The facility should be designed and operated in a manner which is sufficiently flexible to adapt to changing technologies, standards, procedures and knowledge in the field.

- In order to keep abreast of this rapidly evolving field, the literature in the field should be monitored, and exchanges of information among agencies and organizations currently responsible for controlling and operating hazardous waste facilities should be facilitated.

- Wherever possible, some portion of projects should be devoted to researching particular problems and to disseminating the results of that research. Each facility should be treated as a case study with the process of establishing the facility thoroughly documented and widely circulated.

b) Public and Agency Consultation (Section 7)

- Public participation should be an integral part of project management from the outset. Agency and public input should be provided for at all key decision points.

- The effective two-way flow of information is essential to facilitating agency and public participation. The timing, content, and scope of information should be adapted to the concerns and resources of groups and agencies. The information which is provided should focus on community issues, concerns and misconceptions as they arise. Particular care should be taken to explicitly address technical assumptions, and areas of uncertainty which bear on questions of risk and hazard. The information provided should also be readily understandable without being superficial or biased.

- Careful consideration should be given to those characteristics of affected communities which might alter the type, distribution and significance of risks and impacts. Provision should be made for the on-going involvement of groups and organizations whose specialist knowledge can assist in site selection, design and operations.

- The public involvement program should both respond to all agency and group concerns and perceived risks and seek out and anticipate potential concerns and problem areas. A particular effort should be made to ensure that elected representatives and the media are fully informed of the project and its status. If the resources of interest groups are such that they cannot adequately respond to the project, consideration should be given to providing such groups with technical and/or financial assistance.

- The relationship of the landfill to other components of the hazardous waste system should be thoroughly explained. The potential for additional related facilities should be addressed openly from the outset. Local residents and the affected communities should be fully informed concerning methods of monitoring, contingency planning and procedures for regulation and enforcement. Public involvement should also be maintained through closure and after-use planning and monitoring.

- The project should be a collaborative effort between the proponent and the various affected interests. Such an approach would entail negotiating as much of the siting, design and operations of the facility as possible. Although the issues of community character and "social stigma" are difficult to address the public participation program can be designed to respond to the individual concerns and problems which can collectively alter a community's character and image.

c) Site Suitability (Section 8)

- Site suitability criteria should be explicit. They should incorporate agency and public concerns, illustrate the distribution of impacts and highlight critical problems, trade-offs and areas of uncertainty.

- Site selection criteria should be systematically oriented towards minimizing risk and enhancing the potential for community acceptance.

- Sites and areas should be avoided which display the following characteristics:

    - Underlain by potable water aquifers; complex hydrogeologically; located in extensive zones of sand and gravel deposits; subject to rapid erosion and/or inundation; susceptible to landslides; underlain by karst limestone and dolomite deposits; on hilly terrain, particularly adjacent to bodies of surface water; or adjacent to active fault zones.

    - Flood plains, coastal high hazard areas; areas subject to washout, (considering upstream and downstream dams).

    - Environmentally sensitive and significant areas.

- Favoured sites are those where extensive clay deposits are found; those remote from surface bodies of water; with generally flat topography; or underlain by intrinsicially impermeable rock at relatively shallow depth (shales, unfractured igneous rock). In particular, low permeability materials; low natural hydraulic gradients and high capacity for attenuation of contaminants are considered desirable. Although it is generally recognized that clayey deposits of glacial origin have a greater potential for containment, site specific investigations are necessary to confirm the suitability of a particular site. Special attention should be given to the extent of the weathered zone in clays.

- In the process of comparing potential sites consideration should be given to:

    - proximity to bodies of waters and watercourses crossed in the transport of wastes;
    - relative differences in potential impact on flora and fauna;
    - existing and planned population levels (based on air dispersion, hydrogeological and hydraulic analyses);
    - conduits e.g. pipelines which might serve as pathways from the site;
    - sensitive uses where evacuation might pose a problem;
    - the proximity to fire and police back-up and other hazardous uses;
    - potential for and consequences of an accidental release when hazardous wastes are being transported to or from the facility;
    - effects on historical, cultural or archaelogical resources;
    - potential conflicts with local land uses;
    - potential conflicts with local traffic and utilities;
    - noise and visual intrusion.
    - the relative extent to which community concerns can be satisfied.
    - proximity to waste generators, and all weather roads and services.

- Basic facility requirements such as site size (recognizing buffer requirements, local conditions, expansion potential) should be satisfied.

- The interrelationships among meteorological, hydrological, geological and physiographic conditions and the biological environment should be carefully considered. Both direct and indirect impacts, i.e. through ground and surface water contamination and air dispersion, should be taken into account.

d) Wastes for Landfilling (Section 9)

- Landfilling of hazardous wastes should be used as a "last resort" after consideration of other options including waste reduction, recovery or reuse; destruction; or treatment. In many cases these options generate residues for a secure landfill.

- Bulk liquids or containers holding free liquids should not be placed in a secure landfill with the exception of very small containers, e.g. ampoules and containers designed to hold free liquid for use other than storage, e.g. batteries; and lab packs.

- Empty containers should not be placed in a secure landfill unless crushed, shredded or similarly reduced in volume.

- Containers of sludges or solids should only be placed in a secure landfill if they are essentially full. For practical purposes the use of a "90 per cent full" criterion has been proposed by the U.S. Environmental Protection Agency. This standard is equivalent to about 10 cm of freeboard in a typical 45 gallon drum.

- Reactive wastes, defined by the Canadian Task Force on Hazardous Waste Definitions as explosive, ignitable, corrosive or interactive wastes, should not be placed in a secure landfill.

- Sludges should be pretreated or have existing physical characteristics such that they can support compaction equipment. Consideration should also be given to more stringent criteria for compressive strength of sludges.

- Other categories of extremely hazardous wastes should be restricted from secure landfills on the basis of toxicity, persistence in the environment and/or mobility.

- Unacceptable wastes may be pretreated by a range of physical or chemical processes to render them acceptable for secure landfill disposal. Such processes may include the following:

Physical Processes

- Crushing, shredding containers
- Topping up of containers or transfer for bulk handling
- Stabilization to improve load-bearing capacity e.g. addition of absorbents
- Dewatering e.g. filtration, sedimentation, centrifugation, etc.
- Oil/aqueous separation

Chemical Processes

- Detoxification, e.g. cyanide treatment
- Neutralization e.g. acids, alkalies
- Precipitation, e.g. metal hydroxides
- Oxidation/reduction, e.g. cyanide oxidation, chromium (iv) reduction
- Chemical solidification/fixation

e) Design and Construction (Section 10)

- A secure landfill should be designed using sound engineering principles to achieve containment, and to ensure structural stability, it should include the following minimum functional components:

  - A liner on the base of the landfill should be designed and constructed to provide a barrier to prevent the migration of wastes out of the landfill, and at the same time to prevent ground water from entering.

  - A leachate collection and removal system should be placed immediately above the liner to collect and remove leachate from the landfill. The collection and removal system should be designed and operated in such a way as to minimize liquid accumulation within the landfill.

  - A final cover (cap) should be placed on top of the completed landfill to minimize the infiltration of liquids into the landfill, and may also include a gas control system. Long term integrity of the final cover should be assured by post-closure maintenance.

- A drainage control system should be used to minimize the run-on of surface water to the operating part of the landfill, and control runoff of contaminated water from the operating part of the landfill.
- A groundwater monitoring system should be included to permit sampling of ground water upgradient and downgradient of the landfill.
- A series of landfill cells should form the basis for phased construction and operations.

- A design and operations report should form the basis for the preparation of detailed drawings and specifications to be used for construction.
- Landfill liners should be utilized to provide ground water protection not only at sites underlain by relatively permeable soils unless the absence of a liner can be clearly justified. Particular care should be given to weathering effects, which may increase or have increased the effective permeability of natural soils.
- In evaluating candidate liner materials consideration should be given to:

  - Compatibility and durability of the liner in the presence of the waste and waste by-products, e.g. leachate to be contained;

  - Capability of the liner material to contain wastes over the long term;

  - Liner reliability and risk and consequences of failure;

  - Ease of installation, quality control, operation and maintenance.

- In general clay, either in-situ or imported, or polymeric membranes are the preferred liner materials. Both have their advantages and disadvantages: membrane liners afford essentially 100 per cent collection and containment efficiency with an uncertainty regarding their service life; whereas clay liners offer more assurance in long term integrity, but do become saturated and eventually allow a limited flow of leachate to pass through them.

- Using these materials there are essentially three basic design options: the use of in-situ clay as the liner; the use of imported clay or a polymeric membrane to provide a single liner, or the use of in-situ clay/imported clay and/or polymeric membranes to provide a double liner. It is considered here that a double liner of clay and a polymeric membrane provides the most secure level of ground water protection. The differences in the properties of these materials are such that a failure mechanism affecting one of the liners is unlikely to have the same effect on the other liner; essentially the uncertainty in the service life of a membrane liner can be reinforced by the long-term integrity of a clay liner.

- The level of protection required should be based upon the risk and potential consequences of liner failure.

- Design of the landfill liner should thus be based on a desired performance standard rather than a specified design requirement. Performance standards should be defined on a site- and waste-specific basis in terms of a minimum acceptable containment period. Factors to be considered in the design should include the liner thickness, bottom grades, permeability and maximum liquid head that the leachate collection system will allow to develop above the liner.

- Installation of liners should be carried out in accordance with detailed design specifications with special attention to quality control and subgrade preparation, particularly for polymeric membranes.

- For polymeric membranes, a number of liner protection measures should be included in the installation process:

  - soil cover should be placed on top of the liner to protect against weather conditions or equipment;

  - gas vents should be included if gas generation is anticipated beneath the liner;

- if the seasonal ground water table is higher than the liner a drain should be installed to relieve the external hydrostatic head.

Quality control procedures should pay particular attention to field or laboratory testing of field seams, and sealings around penetrations in the liners by pipes and other structures.

- For clay liners a basic requirement is a relatively large proportion of fines (particle size <2 um) in the soil. The most important parameters to be controlled in the installation process should be liner thickness, soil moisture, compaction energy and lift height. The installation should follow generally accepted geotechnical engineering practices. Quality control procedures should include visual inspections and field measurements of clay moisture content and density.

- The leachate collection system should be hydraulically designed to transmit the volume of leachate generated and at the same time to avoid localized build-up of liquid head above the liner. Site-specific or regional water balance considerations are suggested for estimating leachate volumes, while the maximum acceptable head should be considered in the context of the liner performance standards. Design of the system should also consider leachate characteristics and long term integrity of pipe materials, as well as structural stability, operation and maintenance needs.

- In general, on-site treatment of leachate is preferred to off-site, particularly when the leachate is itself characterized as a hazardous waste. The type of unit process to be employed will be highly waste-specific. It is recommended that consideration be given in the planning stage to leachate characteristics, quantity and variability over time in selecting the most appropriate treatment option.

- The final cover (or cap) is designed primarily as a barrier to reduce the potential for liquids entering a landfill. As such its permeability should be less than or equal to that of the liner or base of the site in order to prevent the so-called "bath-tub effect", whereby liquid may accumulate within the landfill after the leachate collection system has ceased to operate. The final cover must also be designed with consideration of a number of other factors. These factors include:

    - gas migration
    - freeze/thaw or dry/soak effects
    - traffic and support requirements
    - vegetative requirements
    - erosion control

  A multi-layer design approach is recommended to meet these requirements and should be tailored to the local conditions and proposed after-use of the site.

- Surface run-on should be diverted away from the active area of the landfill by appropriately designed berms or diversion channels.

- Surface runoff from the active area of the landfill should be handled in the same way as leachate, unless sampling and chemical analysis indicates the water to be acceptable for discharge.

- The use of landfill cells should form the basis for phased construction and operations. It also permits control of drainage and leachate from defined areas of the landfill and can be used for the segregation of wastes as appropriate.

f) Site Layout and Support Services (Section 10)

- For security purposes, a woven steel mesh fence or equivalent of minimum height 2 m should be placed around the site.

- An all-weather access road should be included in the site layout.

- Vegetation and/or berms around the perimeter of the site should be used to screen the site from the public.

- A buffer zone should be included between the active parts of the secure landfill facility and the property boundary. The size of the buffer should be based on site-specific requirements including:

    - containment of spills and adequate buffering of hazardous conditions that might arise from the handling of hazardous wastes;

  - adequate working area for mitigative measures for ground water contamination;

  - space requirements for vegetative screens and/or berms.

- A laboratory should be located on-site with adequate equipment and staff to carry out testing of incoming wastes and for the operational control of any on-site pre-treatment facilities.

- Maintenance facilities should be located on-site with trained staff capable of carrying out routine maintenance of mechanical equipment.

Worker Health and Safety

- Facilities should be provided at a secure landfill facility in accordance with local health and safety regulations including occupational health requirements.

- Site personnel should be adequately trained to respond to emergency situations as well as in safe operating procedures for their routine assignments.

g) Site Operations and Controls (Section 11)

- The handling of wastes at a secure landfill should follow essentially standard operating procedures. On receipt of the waste shipment it should be: checked for appropriate documentation, packaging and labelling requirements; sampled and analyzed to ensure consistency with the documented description; and directed to the appropriate part of the facility. After pretreatment if necessary, the waste is deposited in the landfill under the direction of site personnel, compacted in place, and its location recorded.

- To ensure that site operations are carried out in accordance with standard operating procedures, a series of manuals should be prepared detailing both routine and emergency operations, including inspection and maintenance requirements.

- Before the secure landfill operator/owner contracts with a waste generator to accept a hazardous waste shipment, detailed physical and chemical analysis should be carried out on a representative sample of the waste.

  This analysis is the basis for establishing if and/or how the waste should be handled at the facility. The detailed analysis should be repeated whenever there is a change in the industrial or other process generating the hazardous waste.

- For operational feasibility laboratory tests carried out at the facility on receipt of a waste shipment should be restricted to tests that can be carried out in a relatively short period of time. Should a waste shipment not conform to the documented description, the facility operator/owner may reasonably require more detailed testing either at the facility or elsewhere before accepting the shipment; or may choose to reject the shipment.

- All wastes received at a secure landfill facility should be labelled in accordance with the Transportation of Dangerous Goods Act.

- All wastes received at a secure landfill facility should be accompanied by documentation, which serves three functions:

  - a control document for transportation (mandatory under the Transportation of Dangerous Goods Act);

  - a control document (hazardous waste manifest) for regulatory authorities to ensure that the waste is disposed of appropriately;

  - a control document for the site owner/operator to ensure that the waste is handled appropriately at the secure landfill facility.

- A scheduled inspection and maintenance program should be established for all components of the facility, including berms, drainage works, cover integrity, emergency equipment, security and monitoring equipment. Detailed records of inspection and maintenance activities should be kept.

- Documentation accompanying each waste shipment should be kept at the facility along with a record of its location in the landfill.

- No animals or unauthorized persons should be allowed access to the site. Site security should be maintained by fencing, lockable gates and warning signs; supplemented if necessary by a 24 hour surveillance system.

h) Monitoring (Section 11)

- Monitoring is the means by which the performance of a secure landfill facility is measured, and problems are identified before they become serious. To be effective monitoring must be associated with contingency plans, so that corrective action can be taken if adverse environmental effects are detected.

- Monitoring programs for a secure landfill should include, as a minimum, ground water, surface water, and leachate. In certain circumstances, it may also be appropriate to include air monitoring and biological monitoring to supplement other environmental monitoring activities. Particular emphasis is placed on ground water monitoring since ground water contamination has long-term effects and is difficult and costly to correct.

- Monitoring wells should be used to establish ground water quality upgradient of the site, as a measure of background ground water quality, and downgradient of the landfill to detect possible ground water contamination. Number of wells, depth and monitoring frequency should be established on a site-specific basis. Parameters to be measured initially should be indicator parameters such as specific conductance, TOC, TOH, pH and/or other parameters based on the hazardous constituents of the wastes accepted at the site. In the event that significant contamination is detected, a more detailed monitoring program should be initiated, likely involving a more extensive range of parameters and increased frequency.

- The effects of a landfill on ground water quality should be measured at the edge of the waste management area, i.e. immediately outside any berms, dykes, etc. associated with the landfill. The desired performance standard should require that hazardous constituents in the ground water not exceed:

    - the background level in the ground water for that constituent; or
    - the maximum acceptable levels specified for constituents listed in Canadian Drinking Water Quality, 1978.

- A standard statistical procedure is suggested for determining statistically significant variance of the measured constituents: for discussion purposes, a method based on the Cochran's Approximation to the Behren's - Fisher Student's t-test is proposed (see Appendix G).

- Surface water monitoring should include monitoring of runoff from the active portion of the landfill, as well as the monitoring, both upstream and downstream of all watercourses and drainage channels in the drainage area of the facility. Impacts of the landfill should be assessed using techniques parallel to those described for ground water monitoring.

- Leachate quantity and characteristics should be monitored periodically to provide data for improved control of landfill operations.

- Given the limited information on air emissions from hazardous waste landfills, and the fact that the problem appears to be highly waste-specific, it is difficult to provide guidelines in this area. Air quality monitoring should be considered as part of the environmental monitoring program subject to the types of wastes accepted at the facility, with particular emphasis on their volatility.

- Biological monitoring may be an appropriate technique to supplement other environmental monitoring techniques. The need for its use will be highly site specific.

i) Contingency Planning (Section 11)

- Contingency plans should be prepared to deal both with short-term incidents such as accidental spills, fires and explosions; and the long-term events, primarily those relating to ground water pollution.

- For short-term incidents, the essential elements of the plan are:

  . the organization and responsibilities of facility personnel in implementing the plan;

  - a phased approach involving assessment of the incident, selection of an appropriate response and long-term cleanup;

  - arrangements for local assistance in the event that on-site response capability is not adequate.

- In the event that significant ground water contamination is detected by the monitoring program, corrective action should be taken until the required ground water performance standard is achieved again. The available remedial actions should be reviewed before the landfill begins operation, and appropriate techniques identified for the site setting. Remedial actions may include removal of the hazardous waste or use of ground water control techniques such as:

  - well point or deep well systems
  - drain systems
  - injection systems
  - bentonite slurry trench
  - grout curtain
  - sheet piling cutoff
  - grout bottom sealing

## j) Closure and Post-Closure Care (Section 11)

- Site closure should be undertaken in a manner which minimizes the need for post-closure care and minimizes potential migration of contaminants from the landfill.

- The closure process includes the placement of final cover and vegetation; and decontamination and/or removal of site works, buildings and equipment no longer required.

- After closure, post-closure activities should include:

  - maintenance of final cover and vegetation;

  - continued monitoring of ground and surface water;

  - continued maintenance and operation of the leachate collection and removal system;

  - maintenance of site security, and;

  - maintenance of control movements and benchmarks used to identify individual landfill cells.

- The time period for post closure care remains an area of much controversy. Ideally perpetual care is a desirable concept, but in practice a finite period must be specified. To some extent, the selection of an appropriate period remains a site-specific consideration, which should be linked to the degree of hazard of the wastes that have been disposed off. As a general guideline however, a period of 30 years is proposed for the duration of the post-closure care period.

- Future use of the site of a secure landfill should be controlled. Ideally, the site of the secure landfill facility should include sufficient buffer that restrictions on future development adjoining the site and along major access roads are not required.

- If limitations are required, it is preferable that the site be located in an area where existing planning policies and restrictions limit development to the same degree as would be needed if the facility were established in the area.

- Policies regarding control of future land use should be the product of discussions with municipal representatives and affected land owners. Since there is the potential for the loss of "development rights" through such limitations, consideration may need to be given to additional direct purchase or compensation. Once the policies are established, they should be incorporated in local community plans. All affected owners should be notified.

m) Impacts and Mitigative Measures

- Detailed site investigations should be conducted of; ground and surface water; climate and air quality; biological conditions; and socio-economic conditions. These investigations serve a number of purposes including: establishing baseline conditions; identifying sensitive features; identifying issues and opportunities; and facilitating design, construction, operations, monitoring, contingency procedures and interim and after-use planning.

- The purpose of each site specific study should be clearly defined. Baseline data should be obtained over as long a period as possible in order to facilitate the preparation of projections.

- Interrelationships among environmental components and areas of uncertainty should be identified. Risk to human health and the environment should be minimized. The potential for achieving community acceptance should be facilitated through mitigative and monitoring measures.

- Potential impacts should be predicted in such areas as: surface and ground water; air; natural environment; land use; transportation; social and economic conditions. Attempts should be made to overcome, reduce and compensate for adverse impacts and to enhance benefits.

- Wherever possible areas of disagreement should be negotiated. Benefits and compensation should be provided to those who bear the brunt of the adverse impacts associated with the landfill.

- An open and on-going community consultation program should be maintained through the design, construction, operations, closure and post-closure periods.

- Residual impacts i.e. impacts after mitigative measures should be clearly identified. The significance of each residual impact and potential risk should be interpreted.

- Careful consideration should be given to instituting measures to ensure the financial capability of operators to manage hazardous waste landfill facilities on a day-to-day basis and for clean-up and compensation in the event of an accidental release.

  These measures must cover the operations, closure and post-closure periods. It is probable that a combination of such techniques as bonding, liability insurance and trust funds will need to be instituted. The measures which are adopted, in combination, ensure that operations can be maintained and that financial resources are adequate to meet any health or environmental threat. They should also be oriented towards recovering the costs of operation and liability through disposal rates. The actual combination of techniques adopted will depend on: the types and quantities of wastes; provincial legislation; local site conditions; and the insurance coverage available.

  The point at which the financial responsibilities of the owner-operator end during the post-closure period, e.g. 30 years, should be established and appropriate procedures for refunds and disbursements established. Methods of implementation and administration require particular attention.

### n) Priorities for Future Research and Development

The development of a scientifically-based systematic approach to the disposal of hazardous wastes is a relatively new concept. Numerous areas of uncertainty remain where further research, development and demonstration are required to fully establish design guidelines and criteria to facilitate landfilling without adverse impacts to human health and the environment. Some of these areas are currently under investigation. In Canada, the National Research Council is sponsoring research on the geotechnical aspects of waste disposal. In the United States, the Environmental Protection Agency has an on-going research program in support of its land disposal regulations.

Many issues in the planning of hazardous waste treatment and disposal facilities also remain unresolved or require further attention. These issues include both technical inputs to the process of risk assessment, as well as social considerations and community impacts.

The principal areas where future work is needed are summarized below:

i) Wastes for Landfilling

- A degree of hazard approach should be developed for restricting the landfill of highly hazardous wastes.

- Quantitative criteria and/or waste listings should be formulated to identify and classify waste streams of concern (several examples of such programs exist in the United States). These criteria and/or listings should be developed in the context of hazardous wastes generated in Canada and should address concentration limits where appropriate.

- Standardized testing methods should be adopted for defining hazardous waste characteristics. In particular, a standardized extraction test should be adopted for assessing the leachability of wastes.

ii) Liner Design

- Although extensive research and development have been, and continue to be carried out on liners, there remains much controversy over the long-term effectiveness of the various liner systems. In particular, material types and thicknesses need to be related to hydraulic conductivity and diffusion coefficients for leachate of varying constituents and strengths.

- The testing of liner material using various concentrated chemicals should be extended to actual leachates containing representative concentrations of hazardous constituents. (A limited program of this type is currently under consideration by the U.S. Chemical Manufacturers Association.) Such testing should ideally assess the suitability of liners under field conditions.

iii) Cover Design

- Similar uncertainties apply to cover performance as identified for liners.

- Further research and development are required to address the issues of the type of cover material which will best suit the needs of a facility with respect to moisture and infiltration control, vegetation growth and erosion control. A system of selecting appropriate plant cover to balance evapotranspiration and infiltration potential would be of value. Demonstration projects at field scale are recommended for this purpose.

iv) Environmental Monitoring

- A reference listing of hazardous constituents should be defined for assessing the performance of a secure landfill with respect to ground and surface water protection.

- Because of the limited information on air emissions from hazardous waste landfills, research on air quality at hazardous waste landfills should be undertaken to correlate emissions to waste types and site operations.

v) Subsurface Behaviour

- The transport and environmental fate of many hazardous contaminants is only partially understood particularly in the subsurface environment. There is a need for improved data on ground water flow and attenuation mechanisms, such as adsorption, ion exchange, etc. for assessing the risks of containment breakdown for a secure landfill.

vii) Community Impact

- The many areas of uncertainty which impede risk estimation must be explored further. A particular problem area is the whole question of perceived risks.

- Although there has been a proliferation of general literature on methods of mediation, negotiation and compensation, more attention is required to means of adapting and applying general principles into actual hazardous facility planning. Further attention must also be devoted to methods of involving affected publics.

- A particular effort is required to bridge the gulf between proponents and affected interests. This effort must build upon the shared concern with minimizing risk and satisfying community concerns. It must also, however, be based on an appreciation of the nature and extent of differences which will remain and the rationale for those differences.

# LANDFILLING OF HAZARDOUS WASTES - A DISCUSSION PAPER FOR THE DEVELOPMENT OF GUIDELINES FOR SECURE LANDFILLS

## 1. INTRODUCTION

### 1.1 Background

The problem of finding effective methods of treating, storing and disposing of hazardous wastes is one which is both increasingly urgent and international in its scope and implications.

For many years volumes of hazardous chemical wastes increased without a recognition of problems associated with their toxicity and persistence in the environment. Although a significant scientific effort was involved in the creation of these wastes, much less effort was devoted to developing an understanding of the properties and human health and environmental effects of the wastes. The importance of formulating siting criteria and design and operational procedures specifically for hazardous waste facilities has also only recently been recognized.

A consequence of this lack of foresight has been a number of serious environmental problems involving land disposal, as exemplified in Table 1. In addition to these highly publicized incidents there are a number of existing hazardous waste landfills in North America and Europe with less dramatic, but nevertheless significant problems. In many instances the extent of the problems and the potential for future problems are not known because of inadequate documentation, record keeping and monitoring.

## TABLE 1
## EXAMPLES OF PROBLEMS AT HAZARDOUS WASTE DISPOSAL SITES

- Love Canal, Niagara Falls - a damaged clay cap at a landfill allowed excessive infiltration which, in turn, generated large volumes of leachate with their subsequent migration to adjacent residential areas.
- Hyde Park, Niagara Falls - a landfill site containing significant quantities of highly toxic dioxin, which is leaching via the fissured limestone strata underlying the site and threatening the Niagara River and Lake Ontario.
- Stringfellow Quarry, California - a disposal site using a series of evaporation ponds which overflow during periods of heavy rain.
- Kin Buc Landfill, New Jersey - more than 70 million gallons of chemical wastes were dumped at a site, in direct hydraulic connection with two of the most important aquifers in the region. Major fires and reactions among the various wastes have resulted in emission of toxic fumes to the atmosphere.
- Rocky Mountain Arsenal, Colorado - disposal of pesticides, herbicides and other wastes in unlined holding ponds resulted in extensive ground water contamination.
- Cordova Chemical Corporation, Michigan - discharge of a variety of wastes from manufacture of pharmaceutical intermediates, herbicides and pesticides to the ground or to lagoons dug in sand caused extensive ground water contamination, and loss of the use of ground water as a resource for drinking water supply.
- Upper Ottawa Street, Hamilton, Ontario - liquid industrial wastes were deposited at a site in a poor hydrogeologic setting (recharge area) with a thin veneer of soil overlying fissured dolomite bedrock. Ground water and surface water contamination problems have resulted.
- Private Landfill, U.K. - a load of acidic aluminum sulphate was inadvertently discharged into an excavation already containing some sulphide waste. Hydrogen cyanide was released and the truck driver died in his cab at the landfill site.

The problems which have arisen to date have stemmed from a variety of sources ranging from poor siting and design to inadequate operating and monitoring procedures. As a result workers have been exposed directly. Hazardous wastes have reached the environment through ground and surface water contamination and air dispersion. Once released into the environment, there have been direct and indirect health and environmental effects. In addition, there have been a variety of adverse impacts which have further contributed to the problems often associated with hazardous waste landfills. The sources of these problems, their potential pathways to the environment, and potential impacts are summarized in Table 2.

A further consequence of the problems which have occurred is widespread public fear and mistrust. Fears concerning risks to human health and the environment are often overwhelming in the minds of potentially affected individuals and interest groups. In the past public opposition often has been regarded as selfish parochialism. The legitimacy of many of the public concerns raised is generally acknowledged. However government agencies often have serious difficulties in responding because of the considerable uncertainty respecting the relative merits of different waste technologies and procedures. The long-term risks to human health and the environment is an especially difficult area for providing precise answers.

Hazardous wastes will continue to be generated across Canada. Effective waste management systems are essential to ensure their safe disposal and to avoid damage to health and the environment.

## TABLE 2
## ORIGIN AND IMPACTS OF LAND DISPOSAL PROBLEMS

Potential Problem Sources

- poor siting;
- poor choice of disposal technology;
- failure to adequately address the role of the facility within a larger hazardous waste management system;
- inadequate knowledge of site and area characteristics;
- inadequate design;
- limited knowledge of pathways by which contaminants migrate from the site;
- failure to appreciate problems and risks associated with transporting the hazardous wastes to the site;
- insufficient or inappropriate support services;
- inadequate operating procedures and controls;
- permitting inappropriate development over a closed site;
- failure to maintain an adequate buffer zone;
- inadequate environmental mitigative measures;
- inadequate contingency and emergency procedures;
- inadequate post-closure care and monitoring;
- insufficient or inappropriate public information and consultation procedures.

Potential Pathways to the Environment

- groundwater contamination through leachate migration;
- surface infiltration through subsidence cracks and holes;

## TABLE 2
## ORIGIN AND IMPACTS OF LAND DISPOSAL PROBLEMS
(continued)

- liquids in wastes, rainwater and snowmelt entering the trenches during operations and internal decomposition, adding to the volume of waste water which either accumulates or migrates from site;
- surface water contamination as a result of runoff;
- surface water contamination as a result of flooding;
- release to the environment as a result of seismic damage;
- fire or explosion and transport off-site in smoke, combustion products and fire-fighting water;
- long-term emission of vapours.

Potential Risks and Impacts

- human health effects through direct exposure i.e. workers;
- human health effects through indirect exposure i.e. residents of adjoining areas and along access routes;
- human health effects through biological accumulation or biomagnification;
- displacement of vegetation and destruction and disruption of natural systems and resources;
- displacement of existing land uses and limitation of potential uses on and adjacent to site;
- interference with uses e.g. farm operations;
- social stigma and property value depreciation ;
- traffic increase;
- noise from operations;
- public service and facility requirements;
- aesthetic impacts.

As discussed further in Sections 2 and 3, in the foreseeable future, secure landfilling is a necessary and important component of any comprehensive hazardous waste management system. Thus, the development of guidelines for secure landfills is a priority in Canada if the mistakes of the past are to be avoided and human health and the environment are to be protected.

Notwithstanding previous problems with hazardous waste landfills, the lack of suitable sites in future will ultimately pose a far greater risk to human health and the environment.

At the present time the only secure landfill in Canada is at Sarnia, Ontario, although initiatives are currently being undertaken in Ontario, Alberta, Quebec and British Columbia. Until such time as new facilities are available, the potential for continued illegal disposal directly into the environment and continued storage in unsafe locations remains high.

The long distance transportation of hazardous materials to the United States can not be viewed as even an interim substitute for the establishment of Canadian facilities. Many states are having difficulties in establishing new facilities or even in keeping existing facilities open. More importantly there is the general principle that, although international cooperation is essential, Canada must largely resolve its own hazardous waste problems.

## 1.2 Purpose and Scope of the Study

In view of the need for several secure landfills for hazardous wastes in Canada, it is preferable that a consistent level of environmental protection should be provided across the country. This consistency can be achieved through the acceptance and use of a set of national guidelines for the secure landfilling of hazardous wastes.

It is recognized that the direct responsibility for controlling the siting, development and operation of hazardous waste landfills rests with the provincial governments. Furthermore, some provinces already have some form of guidelines and regulations pertaining directly or indirectly to hazardous waste landfilling. Thus, it is evident that a cooperative Federal-Provincial effort is required if effective guidelines are to be developed. The scope of the guidelines will be defined as a result of this cooperative effort. However, the overall purpose of the guidelines should be to ensure that the siting, design, development and operation of secure landfills be undertaken in a manner which:

- effectively integrates secure landfills and the wastes to be handled at these facilities, within more broadly defined provincial hazardous waste management systems;

- minimizes risk to human health and the environment;

- minimizes potential adverse social, economic and environmental impacts, and enhances potential benefits and community acceptance.

This report is intended to provide the basis for further discussion by the Federal and Provincial governments. As such it identifies and discusses a range of areas related to secure landfilling from which guidelines can be derived.

In defining the scope of this study, it was recognized that any guidelines which might result from federal-provincial discussions should essentially serve as a "code of good practice" rather than as a rigid set of requirements, criteria, standards, or specifications. The adoption of such guidelines therefore would not preclude provincial governments from developing more stringent regulations or requirements to suit local circumstances. They would, however ensure a consistent approach and level of protection for health and the environment from province-to-province. Furthermore, these guidelines could be used, in conjunction with existing regulations, to govern specific aspects of hazardous waste management.

This study consists essentially of a review of the state-of-the-art for hazardous waste landfilling and a discussion of areas where guidelines appear to be required. Thus this study includes the following:

- An overview of the overall hazardous waste management system (Section 2). This section serves to identify the major components of the hazardous waste management system, to demonstrate why secure landfill is a necessary component of that system and to illustrate the interrelationships between secure landfill and the other components of the system.

- Section 3 describes the secure landfill concept together with its major components. Particular attention is devoted to outlining how each component contributes to minimizing the most significant environmental threat associated with secure landfills - the migration of liquids.

- It is essential that the guidelines which are developed extend from the existing provincial guidelines pertaining to hazardous waste landfills. It is also important that the national guidelines reflect major regional differences across the country. Section 4 summarizes the current provincial and federal guidelines and highlights major regional physiographic, hydrogeological and climatic differences. The current federal and provincial guidelines are used as a basis for identifying the areas which have been addressed adequately to date, major inconsistencies, and areas requiring additional treatment.

- Section 5 extends the analysis of potential approaches to the control of secure landfilling to include the approaches employed in the United States and Europe. As with Section 4, the intent of this section is to provide a basis for comparing alternative approaches for application in Canada.

- A central theme which touches on all aspects of the secure landfilling of hazardous wastes is the need to minimize risk to human health and the environment. Section 6 addresses this important area of concern. It considers alternative approaches to the treatment of risk and recommends an approach to risk which is consistent with the current state-of-the-art.

- A further recurrent issue area which directly affects virtually all aspects of the planning, design and operation of hazardous waste landfills is the extent and manner of agency and public consultation. Section 7 is directed towards this important area of concern. Alternative positions with respect to the treatment of public and agency consultation are considered and conclusions and recommendations presented.

- A discussion of the contentious issue of site selection and site suitability is presented in Section 8. The selection of an appropriate site for a hazardous waste landfill can greatly simplify the measures which must be taken during design and operations to minimize risk and achieve community acceptance.

- Section 9 addresses the complex issue of the suitability of different types of wastes for landfilling. Factors for assessing waste suitability are suggested. Restricted waste categories are presented and options with respect to pretreatment are outlined.

- Section 10 describes the major design and construction components of a secure landfill facility.

- Section 11 addresses operations, closure and post-closure concerns.

- Section 12 addresses the issue of community and environmental impacts as well as associated mitigative and monitoring measures. These concerns begin from design and proceed through the closure and post-closure periods.

The major sections of th [illegible] ort are followed by a series of appendices which prov [illegible] onal background material and information.

A number of limitations have been placed on the range of considerations to be encompassed by this study. These limitations, which are listed below, were necessary to ensure that the scope of report was consistent with available resources and remained focused on critical areas of common concern.

Nuclear wastes have been excluded from this study because of the special technical requirements associated with such wastes. This study is not based on original research. Rather, it draws upon available literature and on input received from Provincial agencies, other jurisdictions and industry representatives.

The approach adopted in the review of literature was to focus on what are generally perceived as critical problem areas relative to the landfilling of hazardous wastes. Key aspects of these problem areas, concerns and approaches are highlighted and discussed in this report, with relevant detail provided in the appendices or by cross-reference to more detailed published papers and reports. This approach is consistent with this study's purpose, i.e. a basis of discussion for the development of guidelines. The guidelines, once developed, will be for new hazardous waste landfills. It is anticipated, however, that these guidelines will be of value for landfills already in operation or in the planning or design stages.

## 1.3 Definitions

This section provides definitions of key terms used in this report. These definitions are applicable only for the purposes of this report. Definitions will vary from jurisdiction to jurisdiction. They will also vary depending on whether they are intended for statutory or operational purposes, and whether they are for use by specialists or by laymen.

The ultimate purpose of this study is to provide a framework for discussions leading to national guidelines. The definitions forwarded by the Canadian Task Force on Hazardous Waste Definition have been adopted and are as follows:

- Waste: any substance for which the owner/generator has no further use and which he discards.

- Hazardous waste: those wastes which, due to their nature and quantity, are potentially hazardous to human health and/or the environment and which require special disposal techniques to eliminate or reduce the hazard.

- Storage: condition where waste is contained in a manner that depends on sustained operation or maintenance and monitoring of the facility.

- Disposal: operation where waste is isolated from the environment in a manner that, for safe performance, does not require perpetual maintenance and monitoring.

- Closure: time period after wastes are no longer accepted, during which the owners or operators complete treatment, storage and disposal operations, apply final cover to landfills, establish after-uses and dispose of or decontaminate equipment.

- Post-closure: time period after closure during which owners or operators of disposal facilities must conduct certain monitoring and maintenance activities.

- Landfill Cell: a discrete volume of a hazardous waste landfill which uses an impermeable barrier such as a liner to provide isolation of wastes from adjacent cells or wastes.

- Runoff: rainwater, leachate or other liquid that drains over land from any part of a facility.

- Run-on: rainwater, leachate or other liquid that drains over land into part of a facility.

- Saturated zone: part of earth's crust in which all voids are filled with water.

- Unsaturated zone: part of earth's crust between the land surface and the water table.

- Incompatible waste: those wastes which are not suitable for placement in a landfill because they may cause corrosion or decay of containment materials, or which may, if placed with another waste, result in production of heat or pressure, fire or explosion, violent reaction, toxic dusts, fumes or gases, or flammable fumes or gases.

The Task Force identified two qualitative characteristics by which wastes should be considered hazardous: reactivity and toxicity.

Reactivity

i) Explosive - any waste that might explode with or without an initiating shock.

ii) Ignitable - any waste that represents a fire hazard through absorption of moisture, or by virtue of such properties as flashpoint, spontaneity of combustion or intensity of combustion.

iii) Corrosive - any waste that by virtue of its acidic, caustic or solvent properties, presents a corrosive hazard to living tissue or to its containment material.

iv) Interactive - any waste which contains compounds which can be expected to either bio-accumulate or interact to form other compounds which are hazardous.

Toxicity

i) Lethality - any waste which on exposure results in the occurrence of death.

ii) Carcinogenicity - any waste which on exposure results in a statistically significant increase in the occurrence or extent of malignancy.

iii) Teratogenicity - any waste which on exposure results in a statistically significant increase in the occurrence or extent of physical or functional defects in the developing offspring.

iv) Mutagenicity - any waste which on exposure results in a statistically significant increase in the occurrence or extent of permanent alteration in the gene structure.

v) Pathogenicity - any waste which on exposure results in a statistically significant increase in the occurrence or extent of any disease.

vi) Interfertility - any waste which on exposure results in a statistically significant increase in the occurrence or extent of reproductive failure.

## 2. HAZARDOUS WASTE MANAGEMENT SYSTEM

In discussing secure landfilling of hazardous wastes, it is appropriate to put the use of land disposal and specifically secure landfill into the context of the overall hazardous waste management system. In broad terms the system can be divided into four major components:

- waste generation
- waste collection and transportation
- waste treatment, storage and disposal
- system controls.

The relationships among the elements of these system components is illustrated in Figure 1.

General comments which can be made about the system include:

- Wastes can be generated from a variety of sources including industrial processes, waste treatment residues and discarded chemicals.

- A basic principle is that landfill should be used as a last resort after the options of reduction, recovery, exchange and treatment have been considered.

- An initial sampling and classification of wastes should occur prior to treatment, pretreatment or collection and transportation for storage and disposal.

- Pretreatment and treatment encompasses a broad range of physical, chemical, biological, and thermal processes.

- Pretreatment or treatment can occur at the source of waste generation, at an intermediate collection point, at a waste management facility, or at the land disposal site.

- Wastes may be shipped directly to a waste management facility or via a collection point(s).

- Sampling and classification should occur prior to and subsequent to treatment or pretreatment, as well as prior to and subsequent to collection and transportation.

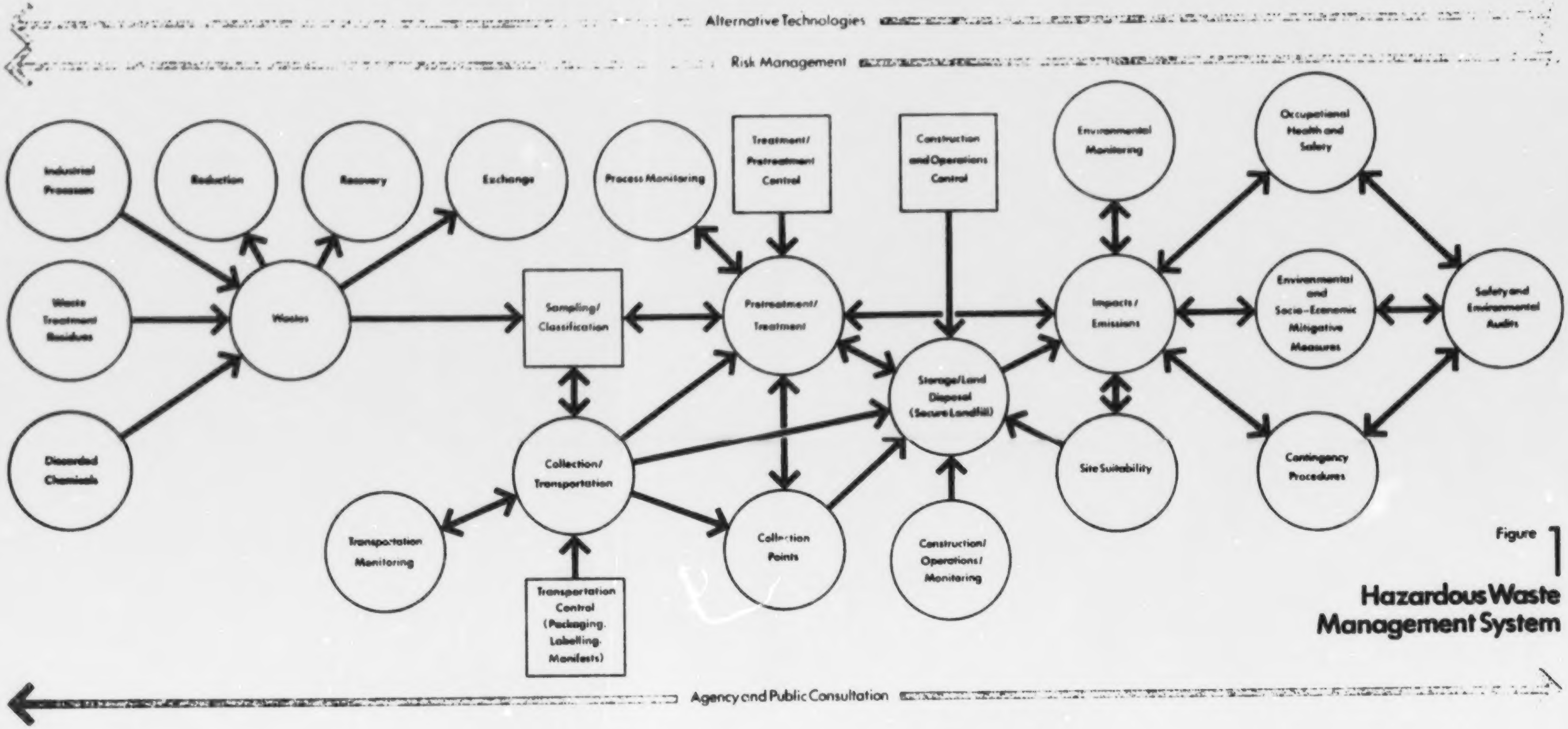
- Despite the use of all available methods of reduction, recovery, exchange and treatment there will always be some residues which must be discharged, to one of the three environmental "sinks"-air, water and land.

- For some of these wastes or discarded chemicals, further treatment is not feasible. As a result, land disposal is the only option.

- The state of technology and regulation for water pollution and air pollution control has evolved at a more rapid rate than land disposal. As a result residues from air and water pollution control techniques ultimately require land disposal.

- An effective site suitability analysis can appreciably reduce the incidence and magnitude of impacts and emissions.

- Although an effective site suitability analysis, together with design, construction and operational



Alternative Technologies
Risk Management
Industrial Processes
Waste Treatment Residues
Discarded Chemicals
Wastes
Reduction
Recovery
Exchange
Sampling/ Classification
Collection/ Transportation
Transportation Monitoring
Transportation Control (Packaging, Labelling, Manifests)
Process Monitoring
Treatment/ Pretreatment Control
Pretreatment/ Treatment
Collection Points
Construction and Operations Control
Storage/Land Disposal (Secure Landfill)
Construction/ Operations/ Monitoring
Environmental Monitoring
Impacts/ Emissions
Site Suitability
Occupational Health and Safety
Environmental and Socio-Economic Mitigative Measures
Contingency Procedures
Safety and Environmental Audits
Agency and Public Consultation

Figure 1

Hazardous Waste Management System

procedures, can substantially reduce the risk of emissions and adverse impacts, these risks and impacts can not be completely eliminated.

- Occupational health and contingency procedures can greatly reduce the potential for human exposure. Various methods of mitigating or compensating for adverse environmental, social and economic impacts can substantially reduce adverse impacts and enhance the potential for community acceptance.

- Monitoring is a critical component of the hazardous waste system. It should occur at several points in the system notably: the monitoring of collection and transportation e.g. safety inspections; process monitoring, e.g. the performance of treatment and pretreatment methods; construction and operations monitoring e.g. liner inspections, cover integrity; environmental monitoring e.g. impacts and emissions to the environment; safety and environmental audits e.g. the adequacy of methods to mitigate adverse impacts and reduce risks.

- Controls also occur at a number of points in the hazardous waste management system notably: the collection and transportation of wastes through packaging, labelling and documentation requirements; the sampling and classification of wastes; the treatment and pretreatment of wastes through criteria for acceptability for water discharge and land disposal; the construction and operations of disposal facilities through design, performance and discharge standards.

- Risk management, the assessment of alternative technologies and agency and public consultation should be integral components of every aspect of the hazardous waste management system.

## 3. THE SECURE LANDFILL CONCEPT

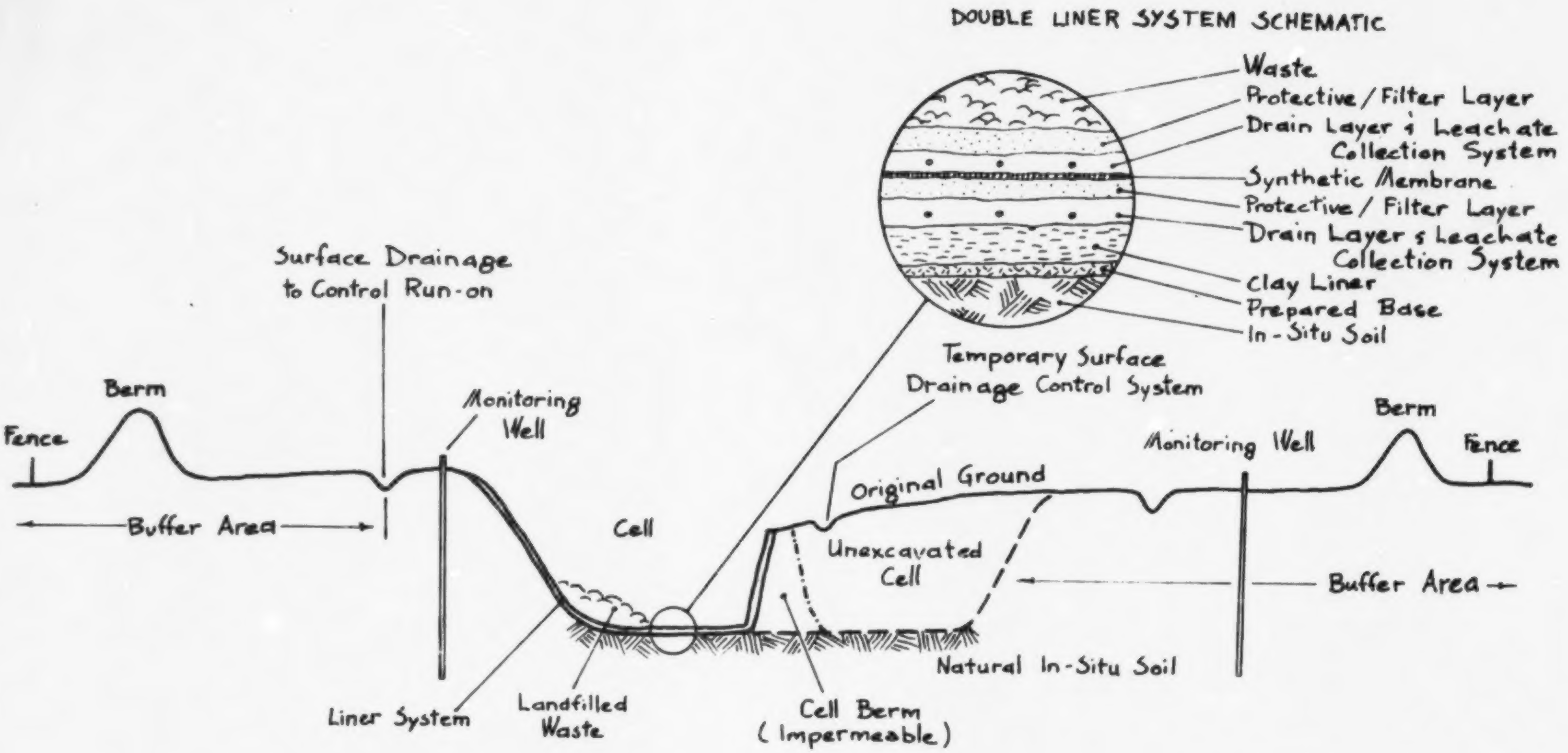
The purpose of the secure landfill is to provide the best available means of prolonging containment of wastes and of minimizing the amount of contaminants released to the environment in the long-term.

A secure landfill is generally understood to be a disposal site for hazardous wastes only, as distinct from the concept of co-disposal, whereby hazardous and industrial wastes are mixed with municipal refuse. The containment principle of secure landfill should also be distinguished from controlled leakage and the use of natural attenuation in the soil as the primary environmental protection mechanism.

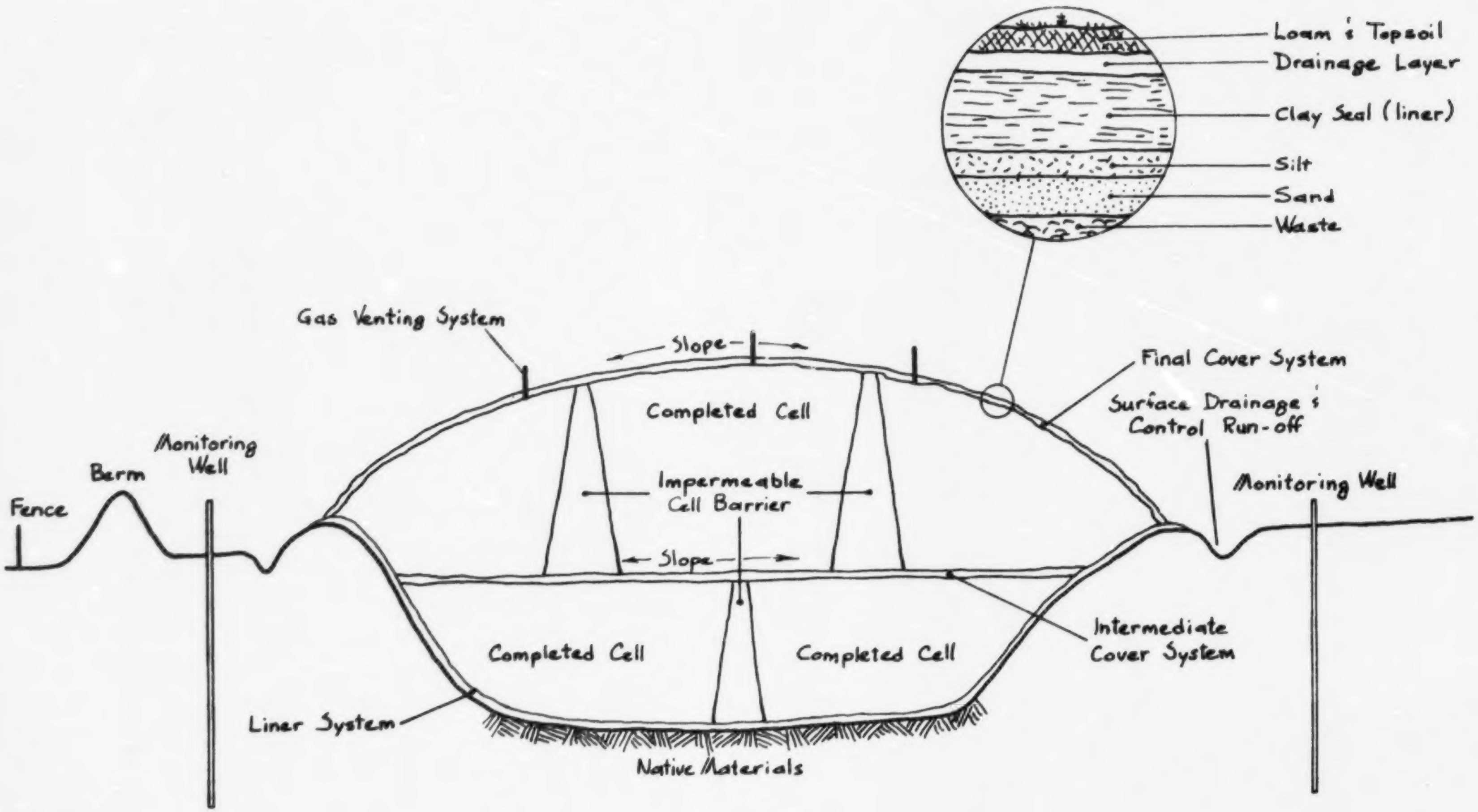
The secure landfill concept is based on the recognition that the most significant environmental threat is migration of liquids containing hazardous constituents into ground water. Outlined below is a brief description of the major components of a secure landfill, with a particular emphasis on the ways in which they avoid the contamination of ground water. Figures 2 and 3 illustrates how each component serves to minimize the potential for ground water contamination.

- A liner on the base of the landfill is designed and constructed to provide a barrier to prevent the migration of wastes out of the landfill and at the same time to prevent ground water from entering.

- A leachate collection and removal system immediately above the liner collects and removes leachate from the landfill. The collection and removal system is designed and operated in such a way as to minimize liquid accumulation within the landfill.


DOUBLE LINER SYSTEM SCHEMATIC
Waste
Protective / Filter Layer
Drain Layer & Leachate Collection System
Synthetic Membrane
Protective / Filter Layer
Drain Layer & Leachate Collection System
Clay Liner
Prepared Base
In-Situ Soil
Surface Drainage to Control Run-on
Temporary Surface Drainage Control System
Fence
Berm
Monitoring Well
Original Ground
Monitoring Well
Berm
Fence
Buffer Area
Cell
Unexcavated Cell
Buffer Area
Natural In-Situ Soil
Liner System
Landfilled Waste
Cell Berm (Impermeable)

A - A Schematic Cross-section of a Secure Landfill
Figure 2


Loam & Topsoil
Drainage Layer
Clay Seal (liner)
Silt
Sand
Waste
Gas Venting System
Slope
Final Cover System
Surface Drainage & Control Run-off
Completed Cell
Monitoring Well
Berm
Fence
Impermeable Cell Barrier
Monitoring Well
Slope
Completed Cell
Completed Cell
Intermediate Cover System
Liner System
Native Materials

**Schematic of a Completed Secure Landfill**
**Figure 3**

- A final cover (cap) placed on top of the completed site minimizes the infiltration of liquids into the landfill, and may also include a gas control system. Long-term integrity of the final cover is assured by post-closure maintenance. The permeability of the final cover is less than or equal to that of the liner in order to prevent the build-up of liquid head within the landfill after the leachate collection has ceased operating. This is the so-called "bath tub effect".

- A drainage control system minimizes run-on of surface water to the operating part of the landfill, and controls runoff of contaminated water from the operating part of the landfill.

- A series of landfill cells forms the basis for phased construction and operations. It also permits control of drainage and leachate for limited areas within the landfill and can be used for the segregation of wastes as appropriate.

- A monitoring system and contingency plan assess the impact of the landfill on ground water and surface water in the vicinity of the site and ensure appropriate action in the event of potential ground water contamination. In this way the risk of off-site contamination of ground water is minimized.

The measures described above, in combination, provide a high level of long-term ground water protection. It is, however, recognized that there remain risks and uncertainties concerning the available technology for liners, caps and leachate collection systems. As a result waste containment cannot be guaranteed in perpetuity. It is for this reason that monitoring and contingency planning is such an important component of the secure landfill concept.

# 4. THE CANADIAN CONTEXT

## 4.1 Existing Regulations and Guidelines

### a) Introduction

Existing regulations and guidelines relevant to hazardous waste landfills were requested from federal and provincial agencies and authorities. In addition to federal input, responses were obtained from the Provinces of Nova Scotia, Quebec, Manitoba and Alberta. (Appendices A and B). In addition, available guidelines were obtained from the Province of Ontario.

The intent of a review of existing guidelines was to establish a basis for the formulation of Canadian guidelines recognizing the activities of the provinces in the management of hazardous wastes.

In this section an overview of those parts of existing federal and provincial regulations and guidelines which pertain to hazardous waste secure landfills is provided. Conclusions are then drawn concerning the implications for the formulation of national guidelines.

### b) Overview of Existing Guidelines and Regulations

Two Provinces, Quebec and Nova Scotia, have prepared guidelines for Hazardous Waste Landfills. Quebec's guidelines are in the Form of Regulations. Nova Scotia has prepared draft guidelines. The major provisions of the Nova Scotia and Quebec guidelines are highlighted in Table 3. The scope of

## TABLE 3

## SUMMARY OF SELECTED PROVINCIAL REGULATIONS AND GUIDELINES

| JURISDICTION/ AUTHORITY | TITLE OF GUIDELINE REGULATION | STATUS | SITING/ LOCATION | DESIGN | OPERATIONS | MONITORING | MISCELLANEOUS |
|---|---|---|---|---|---|---|---|
| Nova Scotia Dept. of the Environment | Guidelines for the Selection of Chemical Waste Landfills | Draft | -thick, relatively impermeable formations such as large area clay pans<br>-if not, then soils to have high clay and silt content with specific parameters as outlined in Design<br>-landfill base to be above historical high ground water table<br>-no hydraulic connection between site and standing or flowing surface water. | -in place, soil thickness, 4 feet<br>-compacted soil liner thickness, 3 feet<br>-permeability $10^{-7}$ cm/sec<br>-artificial liner thickness > 30 mil<br>-leachate collection monitoring<br>-leachate to be either treated to acceptable limits or disposal of by a provincially approved method<br>-simple gravity leachate collection system to be installed over liner when semi-solid or leachable solid wastes are placed in a relatively thick, unsaturated, homogenous layer of low permeability soil<br>-compound leachate collection system to be installed under primary liner and above secondary liner when semi-liquid or leachable solid wastes are placed into relatively permeable soil<br>-suction manometers or porous "stones" to be installed along sides and bottom of waste disposal facility when relatively permeable unsaturated soil is encountered adjacent to or below disposal facility. | -containers of toxic materials to retain their structural integrity<br>-operations plan to be submitted for approval outlining record keeping, excavation and backfill, leachate collection system, monitoring, security, etc.<br>-incompatible wastes to be segregated<br>-3 dimensional burial coordinates of wastes to be kept on record. | -baseline sampling required<br>-monthly sampling during landfill operations<br>-indefinite period of sampling after closure with a frequency no less than once every six months<br>-3 ground water sampling points only if underlying earth material is homogeneous, impermeable and uniformly sloping in one direction<br>-parameters to be analyzed to be established by Department of the Environment. | Support Facilities<br>-6 foot woven mesh fence, wall or similar device required<br>-roads to be adequately maintained. |

TABLE 3
(continued)

| JURISDICTION/ AUTHORITY | TITLE OF GUIDELINE REGULATION | STATUS | SITING/ LOCATION | DESIGN | OPERATIONS | MONITORING | MISCELLANEOUS |
|---|---|---|---|---|---|---|---|
| Quebec Ministry of the Environment | Guidelines for Land Disposal of Industrial Residue Containing Toxic Substances | Regulation | -no underground conduit or pipe under landfill area<br>-for Class I, 350 metres from areas zoned for agriculture, commercial, residential or a mix, and other non-zoned areas<br>-for Class II, 200 metres from areas zoned for commercial, residential or a mix<br>-for both Classes - 3 km from airport and 100 m from a public road:<br>.150 m from flood plain<br>.300 m from a lake<br>.more than 10 m from adjacent property owner<br>.1 km from potable water well. | -for Class I, permeability of $10^{-4}$ m/d for depth of at least 6 m from base of landfill area or $10^{-3}$ m/d with minimum depth of 10 m from the base of the landfill<br>-for Class II, permeability of $10^{-3}$ m/d for 6 m depth or $10^{-2}$ m/d for 10 m depth<br>-for Class I, surrounding soils to be $10^{-3}$ m/d permeability; for Class II, $10^{-4}$ m/d<br>-1 m final cover exhibiting same permeability as landfill liner<br>-minimum slope, 2%<br>-maximum slope, 4%<br>-vegetation or final cover to be maintained for 2 years after closure<br>-surface water to be kept away from wastes<br>-final contours to match existing contours or surrounding topography. | -landfilling to be done in cells or trenches<br>-record keeping to include types of wastes, quantity, name of hauler, name of waste generator<br>-surface water to be pumped out and treated if required<br>-wastes should be disposed directly into cells or trenches. | -monitoring wells required for Class I only<br>-for Class I, semi-annual sampling to include toxic substances and other physical parameters | Support Facilities<br>-fencing, tree screening, berms<br>-perimeter to be fenced and signed<br>-all access roads to be provided with gates. |

those guidelines together with the guidelines and discussion papers of the Provinces of Ontario and Alberta are described below.

Nova Scotia

Although the title of the draft guidelines for Nova Scotia specifically pertains to chemical waste landfills, they encompass a much broader range of concerns. Consideration is, for example, given to the design of liners (including their associated permeabilities) and leachate collection systems. The guidelines recognize the potential need for double liners and collection systems. Operational considerations for an explicit operating plan and record keeping are also addressed. The draft guidelines recognize the importance of monitoring requirements in the overall disposal operation.

The draft guidelines are quite comprehensive in addressing the physical components of landfills. They do not, however, relate the physical criteria to the types of wastes that can be landfilled nor to the degree of hazard associated with the landfill of particular wastes. Permeabilities, for example, are not related to performance standards for ground water quality. Other areas not addressed include cover requirements, maintenance during post-closure, and leachate treatment and disposal.

The full text of the draft guidelines for Nova Scotia is provided in Appendix C.

In addition the Province of Nova Scotia has prepared guidelines for the operation and selection of solid waste disposal sites. These guidelines include:

- standards for location, maintenance and operation of a landfill site;
- standards for location, maintenance and operation of an incineration site;
- standards for the location, maintenance and operation of a dump.

## Quebec

Quebec's guidelines for the disposal of industrial wastes include two classes of sites dependent on the type of wastes landfilled. The Quebec guidelines generally cover all basic design and operation considerations of landfills. Design considerations include permeabilities, slopes and final cover requirements. The guidelines do not specify liners and leachate collection systems as mandatory requirements as is the case in the Nova Scotia guidelines. Operational needs are considered including record keeping and the concept of cells. Liquids are specifically forbidden unless pretreated.

## Manitoba

Manitoba has regulations under the Clean Environment Act governing the disposal of solid wastes but does not have guidelines or regulations directly relevant to the disposal of hazardous wastes. As a result the criteria for design, operations and maintenance are relatively less rigourous than those of either Nova Scotia or Quebec. Primary considerations such as soil permeabilities, requirements for liners and leachate collection systems, and monitoring needs are, for example, not specified. Classifications of disposal sites are provided on the basis of populations served rather than in the terms of the types of materials for disposal. Emphasis has been placed on operational requirements rather than on siting or design.

Manitoba also has guidelines for the disposal of asbestos wastes. These guidelines include consideration of site selection and pre-treatment or pre-disposal procedures. They also include the designation of hazardous wastes if they contain ammonia nitrate, hydrochloric acid, nitric acid polychlorinated biphenyls or sulphuric acid.

## Ontario

Ontario does not have guidelines which specifically address hazardous waste landfills. It does, however, have a number of guidelines which consider several of the concerns which would need to be addressed in the planning, design and operations of a secure landfill.

The major relevant areas addressed by these guidelines are noted below:

Guidelines for Response to Environmental and Environmental Health Emergencies, November 1978.

- definition of environmental emergency;
- evaluation of hazard;
- containment and countermeasures.

Guidelines for Environmental Protection Measures at Chemical Storage Facilities, October 1978.

- definitions;
- containment systems for storage tanks, location, volume;
- drainage collection and disposal;
- design criteria for dykes;
- guidelines for storage of gases and volatile liquids.

Perpetual Care for Waste Management Facilities, Interim Report, August 1979.

- funding for operation at closure, monitoring and maintenance;
- liability insurance;
- perpetual care including contingencies.

Some Hydrogeologic Considerations in Landfill Site Evaluation, July 1977.

- leachate production and migration;
- soil permeabilities and ground water flow systems;
- leachate control facilities.

Guidelines for the Establishment, Operation, Management, Maintenance and Closure of Landfilling Sites in Ontario.

- considerations for hydrogeology, design, operation and maintenance;
- liner (clay preferred);
- leachate collection system;
- gas control;
- site facilities and services;
- site closure.

In addition to the guidelines identified earlier, the Ontario Ministry of the Environment established a seven point program for dealing with liquid industrial wastes. The program established in 1977 is a Ministry policy statement addressing the question of comprehensive short and long-term management of industrial wastes in Ontario.

Briefly, the seven points are:

1. Facilities

    - private sector involvement;
    - planning for long-term requirement for facilities and sites;
    - acquisition of sites.

2. Interim Measures

    - development of guidelines for treatment and disposal;
    - secure landfills for liquid wastes where no alternative technologies exist;
    - monitoring and control for landfilling;
    - interim storage for such wastes as PCBs.

3. Way-Bill Monitoring

   - computerization of way-bill system to account for movement of wastes.

4. Classification of Waste

   - review of classification systems in other jurisdictions.

5. Regulations

   - prohibition of direct landfilling of liquid wastes;
   - directing wastes to appropriate types of treatment and disposal technologies;
   - registration of wastes;
   - creation of a fund for perpetual care.

6. Perpetual Care

   - long-term commitment for the protection of public and the environment through surveillance, maintenance and contingencies.

7. Trans-boundary Movement

   - dialogue to enhance economic and effective disposal of waste through inter-provincial movement.

Several points of the program have already been instituted. The way-bill system has been established and will be in full operation shortly. Guidelines have also been established for storage facilities and perpetual care as noted earlier. In addition, the creation of the Ontario Waste Management

Corporation has resulted in the transfer of some of the points in the program to the newly created body. These include long-term liquid waste management plan, site selection, and waste classification.

## Alberta

At the present time, Alberta Environment is developing a set of criteria for the total management of hazardous wastes. The development of the criteria are at a preliminary stage and therefore, have not been published as yet. The Environment Council of Alberta, however, has issued a document entitled "Public Hearings on Hazardous Waste Management in Alberta, Report and Recommendations" in December 1980. In the report, a broad range of issues related to hazardous waste management were discussed. Included are:

- definitions of hazardous waste and associated terms;
- waste classifications;
- waste inventory;
- environmental and social setting;
- available hazardous waste treatment technologies;
- transportation of hazardous goods;
- economics of transportation, treatment and disposal;
- siting criteria;
- management system, licensing, manifest, liability.

In the document, the Council made a number of recommendations with respect to legislative control, system design and site selection, organization and function, treatment, licensing and the manifest system. The complete set of recommendations are given in Appendix D.

Canada

The Government of Canada has prepared two sets of guidelines of relevance to the issues to be addressed in this discussion paper. The guidelines for the Management of Waste Materials Containing Polychlorinated Biphenyls (PCBs), August 1978 considered the identification, collection, transportation, storage, treatment, and disposal of PCBs. The guidelines on Central Collection and Storage Facilities for Waste Materials Containing Polychlorinated Biphenyls (PCBs), November 1978 include consideration of site selection, design, security, operation, record keeping, inspection, maintenance and closure.

### c) Implications for the Development of Guidelines

The following conclusions have been drawn from the existing Provincial Guidelines and Regulations:

- no consensus exists among provincial agencies on the framework and substance of hazardous waste management guidelines/regulations;

- emphasis to date has tended to be placed on design standards rather than performance standards;

- risk assessment has generally not been addressed in guidelines/regulations;

- siting and location of facilities vary - Quebec has specified distances from such features as airports, roads, adjacent property owners etc. Nova Scotia has emphasized ground water table and types of in-site materials;
- site selection criteria are generally not well developed;
- liner requirements vary from a possible double liner system to reliance on native materials for containment;
- native clay and liners appear to be preferred although Nova Scotia will accept an artificial liner as an alternative;
- leachate collection systems are not necessarily a mandatory requirement for jurisdictions such as Quebec;
- final cover systems are not as well defined relative to liner systems; Quebec requires final cover to exhibit the same permeabilities as liners but Nova Scotia does not include covers in its draft guidelines;
- the concept of cells is recognized by Quebec;
- incompatibility of wastes is recognized by Nova Scotia;
- operational considerations are well addressed with emphasis on good record keeping, and operational controls;

- monitoring is generally recognized as an integral part of hazardous waste management although the degree of emphasis varies from jurisdiction to jurisdiction: Nova Scotia requires monitoring on a monthly basis during landfill operations. Quebec requires monitoring semi-annually for Class I sites only;

- parameters for monitoring are not specified;

- requirements for contingency plans are generally not well specified; both Nova Scotia and Quebec have not addressed contingency plans;

- requirements for support facilities are generally consistent from jurisdiction to jurisdiction and emphasize security and good operations (roads, berms, fencing).

## 4.2 Regional Considerations - Hydrogeology and Climate

Hydrogeological conditions have a significant bearing on the choice of site and the design of a secure landfill.

The low hydraulic conductivity of clay deposits makes them especially suitable for the siting for secure landfills. Such deposits are not uniformly distributed throughout all regions of Canada. Consequently some parts of the country may provide more favourable opportunities for secure landfills than others. In particular, the vast majority of lands characterized by extensive clayey deposits occur within the interior plains of Alberta, Saskatchewan and Manitoba; the Great Lakes Lowland; the Hudson Bay Lowland; the Cobalt Plain of Ontario; and the St. Lawrence Lowland of Quebec.

The existence of extensive clayey soils in Alberta, Saskatchewan, Manitoba, Ontario and Quebec offers considerable flexibility in siting secure landfills in these provinces. Within the Maritime Provinces, Newfoundland and British Columbia there will exist a smaller number of suitable hydrogeological sites. Similarly, within the discontinuous permafrost zone in the Yukon and Northwest Territories, possible non-permafrost sites may exist for small secure landfills; e.g. in the clay deposits found in the Canadian Shield around Yellowknife. Secure landfills do not appear to be feasible in the continuous permafrost zones of the Canadian north.

Apart from the extreme cold of the Arctic Islands and the continuous permafrost of the mainland, climate does not preclude the use of secure landfill in Canada. In relation to minimizing the potential for producing leachate, the most suitable regions of Canada are those with a combination of low annual precipitation and high annual evaporation. These conditions are found in southeastern Alberta, southern Saskatchewan and southern Manitoba together with northwest British Columbia and northern Alberta. Thus the dry climate of the Prairies makes them ideal for the use of secure landfill. The excess of precipitation over evapotranspiration increases with distance from the Prairies and proximity to the Atlantic Ocean. The potential for leachate production will increase accordingly across Ontario, Quebec and the Maritime Provinces.

The Coastal Mountains of British Columbia promote a wet climate for the coastal region. They also result in a relatively dry climate in interior British Columbia. Thus a relatively small excess of precipitation over evapotranspiration occurs in interior British Columbia, and makes it more suitable for secure landfilling than the coastal region.

Annual snowfall in Canada is relatively low in the southern prairies and generally increases eastwards across Ontario, Quebec and the Maritimes. Southern interior British Columbia receives approximately the same snowfall annually as the southern prairies. In relation to secure landfills, lower snowfalls facilitate operation and also minimize the potential for leachate production.

In the Canadian context hydrogeological and climatological factors do not appear to preclude the use of secure landfills in any province or territory, except for the Arctic Islands and the continuous permafrost zone of Northern Canada.

Good hydrogeological conditions and the most favourable climatological conditions exist in the Southern Prairies. Good hydrogeological conditions and reasonable climatological conditions exist in Ontario and Quebec. Slightly less favourable climatological conditions exist in the Maritime Provinces. The southern interior and the northwest of British Columbia also offer good climatological conditions.

# 5. OVERVIEW OF APPROACHES TO SECURE LANDFILLING

## 5.1 Regulatory Approaches

The regulatory approach taken to the landfilling of hazardous wastes in other jurisdictions varies considerably depending upon their institutional structures and past environmental problems with land disposal of hazardous wastes. Points of particular relevance to the Canadian situation have been taken from European and U.S. regulations. The following overview of other jurisdictional approaches is intended to serve as a basis for the formulation of Canadian guidelines.

### a) Europe

In Europe there are a number of European Community Directives concerning "toxic and dangerous wastes". However, these directives make no specific reference to land disposal. Although the objectives of the member states are similar in terms of ground water protection, there are some large differences in the methods of applying the directives.

In the U.K. the Control of Pollution Act establishes "Special Wastes" regulations, which provide a listing of wastes together with criteria for the inclusion of wastes considered "dangerous to life". While these regulations recognize that some wastes are much more dangerous than others and should be handled differently, (as well as providing a waste "tracking" system), they do not specify particular land disposal procedures or restrictions. The control of land disposal is handled regionally on a case-by-case basis controlled by individual site licencing requirements.

The U.K. policy also encourages the "sensible" landfill of hazardous waste and the use of natural soil attenuation, subject to certain controls on site selection, waste types, operations and monitoring. For instance, there are a number of substances which in significant quantities would not normally be disposed of in landfills, including:

- low flash point organic solvents;
- highly corrosive wastes, e.g. mineral acids and strong alkalis;
- bulk disposal of highly toxic water soluble wastes;
- persistent or very volatile toxic wastes;
- wastes with offensive odours;
- "chemically incompatible wastes, if their segregation cannot be guaranteed";

The definition of "significant quantities, highly corrosive" etc., is again handled on a site-specific basis.

In other European countries, the emphasis of land disposal is much more on containment than attenuation. Again there are variations in the approaches adopted. In Denmark oily residues are permitted in the hazardous waste management facility, Kommunekemi. The facility includes a secure landfill for incinerator residues and filter cakes from treatment processes and other wastes. At the other extreme, the Dutch Chemical Waste Act prohibits the disposal of chemical wastes on land and the export of wastes is a normal procedure.

In Germany, which has a much larger chemical industry than Denmark or the Netherlands, waste disposal is controlled regionally by Länder. Public sector involvement in the ownership of waste management facilities is not uncommon, and waste producers may be required to send their wastes to particular regional facilities. Regulations have been developed which establish three categories of industrial wastes:

- Group I: wastes which can be landfilled, provided that certain precautions are taken to avoid contamination of soil, water and air, e.g. acid resins, tar residues and oily earth.

- Group II: wastes of organic origin which can be incinerated with or without pretreatment, e.g. used oil, waste oil, plastics, solvents.

- Group III: wastes of an organic and inorganic nature which may be landfilled only after chemical or physical pretreatment, e.g. acids, alkalis, caustic, water soluble salts of heavy metals, galvanizing sludges.

As in the U.K., site licencing controls are the basis for more specific details of waste acceptability and landfill design and operations etc., but containment is the preferred approach for design. Although there are no specific design requirements for the secure landfilling of hazardous wastes, the German guidelines for landfilling of municipal wastes (see Appendix E) include some items which would likely also apply to hazardous wastes:

- liners (natural and synthetic) are required in the absence of suitably impervious soils, and should be at least 60 cm thick and compacted so that permeability is at least $10^{-6}$ cm/sec.;

- a landfill site with liners or naturally impervious soils must include a leachate collection system.

b) United States

The United States approach to controlling land disposal of hazardous wastes has taken a somewhat different course to that in Europe. The United States has decided on a very detailed approach to the development of land disposal regulations. Over some three and one-half years, the U.S. Environmental Protection Agency has considered a number of options starting with design standards at one extreme and site-specific risk assessment at the other end of the spectrum. Other options such as containment standards and location standards have been considered during the evolutionary process leading up to the most recently proposed regulations of 26 July 1982.

The most recent Regulations should be considered in conjunction with the U.S. EPA proposed definitions of hazardous wastes (see Appendix F). The Regulations are an "interim final rule with request for comments", i.e. still subject to change, but as proposed consist of a mixture of performance standards for design and operations, and ground water monitoring and response requirements. The former is intended to ensure that owners or operators minimize the formation of leachate and the migration of leachate to the adjacent subsurface soils, and to ground water and surface waters. The latter is intended to ensure that owners or operators detect any ground water contamination, and perform corrective action when such contamination threatens human health and the environment.

The design and operating standards require landfills to have liners to prevent migration of wastes to the subsurface soil and ground water or surface water during the active life of the landfill. Leachate collection and removal systems are also required to minimize leachate remaining after closure. They must be maintained throughout a post-closure period (30 years) or until it can be demonstrated that wastes from the landfill pose no threat to human health or the environment. The site must also be engineered to prevent run-on from the 25-year storm. At closure the landfill must be provided with a final cover and maintained and monitored for ground water contamination during the post-closure period.

The ground water protection requirements consist of a three stage program to detect, evaluate and correct ground water contamination during the active life of the landfill plus a compliance period that would be designated in the permit.

The first stage of the program requires the installation of a ground water monitoring system at the waste boundary (up-gradient and down-gradient) to monitor ground water for parameters that would indicate whether a leachate plume has reached the waste boundary. If a plume is detected, a second stage of compliance monitoring is initiated for a much broader range of hazardous constituents.

The point of compliance is chosen as the edge of the waste management area, defined as that part of the facility used for hazardous waste treatment, storage and disposal activities, including dykes, berms, etc.

The results of the compliance monitoring are compared against a ground water protection standard, which requires that the hazardous constituents not exceed the following concentration limits:

- background level in the ground water for any hazardous constituent, or

- the maximum concentration level for the hazardous constituents covered by drinking water regulations, or

- any other limit that can be shown by the operator not to harm human health and the environment.

If the ground water protection standard is violated, corrective action must be undertaken and continued until the standard is complied with. Such corrective action consists of removal of contamination or in-situ treatment of hazardous constituents.

The Regulations provide an option whereby the ground water monitoring and response requirements can be waived by complying with more stringent design and operation standards. These standards include a double liner system with a leak detection system between the two liners. If a leak is detected it must be either repaired or the unit becomes subject to the ground water monitoring and response requirements. The ground water monitoring and response requirement can also be waived if it can be shown that the hydrogeologic regime of the site is such that ground water contamination cannot occur during the compliance and post-closure care period.

In assessing the results of the ground water monitoring the compliance point data should be compared with the background data using Cochran's Approximation to the Behrens-Fisher Student's t-test. This standard statistical procedure is described in Appendix G.

Some additional points of importance included in the regulations or implied by them are as follows:

- The use of clay liners will likely not be acceptable since their use will allow some penetration of leachate into the liner and eventually flow out of it; which would not be consistent with the goal of "...preventing wastes from passing into the liners during the active life...". In contrast, a membrane liner can achieve essentially 100 per cent collection efficiency. (The use of a membrane liner may be in direct contradiction with California regulations which specifically prohibits artificial membranes.)

- Because of its longer life, clay is preferred for the construction of the landfill cap. However, in order to avoid the "bath-tub" effect, the cap must be as impermeable as the liner. If the landfill is lined with a membrane liner, in effect this represents a requirement for a two layer cap consisting of both synthetic membrane and clay.

- Bulk liquid waste will be allowed as long as the landfill has a liner, and leachate collection and removal system.

- Liquid wastes in containers will not be permitted, unless pretreated to render them solid. Similarly ignitable or reactive wastes will not be permitted, nor will incompatible wastes be allowed in the same landfill cell.

These Regulations will, in many cases, be adopted and implemented by the individual States. In some cases, certain States have existing Regulations for land disposal or are proposing more stringent Regulations, particularly with respect to waste suitability. The States of California, New York and Minnesota have been selected as examples of such programs, and selected highlights summarized in Appendix H.

### c) Implications for Canadian Guidelines

The following conclusions have been drawn from the review of other regulatory agencies outside Canada:

- Generally, regional, rather than national control of hazardous waste management is exercised.

- The U.K. encourages the use of soil attenuation as the primary mechanism for leachate control, rather than containment using liners and leachate collection systems.

- Containment is emphasized in the rest of Europe although approaches vary.

- Germany requires liners and leachate collection systems.

- The U.S. has taken a more detailed approach than in Europe; a number of options ranging from design standards to site specific risk assessment have been considered.

- The new proposed regulations for U.S. encompasses a mixture of performance standards for design and operations and ground water monitoring and response requirements.

- The U.S. requires a liner and a leachate collection system to be maintained over a 30 year post-closure period; preference has been given to artificial liners over clay.

- Detailed monitoring requirements are proposed for U.S. including monitoring during the active life and after-closure; contingency plans are required.

- Monitoring can be waived if more stringent design and operations standards are adopted.

- Clay for the final cover or cap is preferred with permeabilities the same as the liner.

- Certain states in the U.S. have adopted more stringent standards.

## 5.2 Design Examples

A number of secure landfills have been chosen and a summary of their major design features prepared to provide some indication of the current trends in the design and operating characteristics of secure landfills (see Table 4). The selected sites are as follows:

- Cecos (New York)
- S.C.A. (South Carolina)
- DuPont (New Jersey)
- Gallenbach (Bavaria, West Germany)
- Bayer (Leverkusen, West Germany)
- Kommunekemi (Nyborg, Denmark)

It is emphasized that these landfills are not necessarily typical or representative, but were those for which information could be easily obtained. Nevertheless they do demonstrate the diversity of design approaches to the liner and cap component of the secure landfill.

## TABLE 4

## SUMMARY OF MAJOR DESIGN FEATURES OF SELECTED SECURE LANDFILLS

| SITE | LOCATION | SIZE/CAPACITY/LIFE | HEIGHT | GEOLOGY | LINER TYPE | LINER THICKNESS | PERMEABILITY | CELL CONSTRUCTION | LEACHATE COLLECTION | LEACHATE DISPOSAL | FINAL COVER | MONITORING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CECOS NO. 3 | New York | 385 acres total; No.3 - 5 acres | not available side slope: 3:1 maximum | clay | primary - imported clay over in-situ clay<br>secondary - high density polyethylene | primary - 10 feet<br>secondary - 80 mil | primary - $10^{-7}$ cm/sec.<br>secondary - not available | 5 cells plus subcells | per subcell during operation, standpipe after closure | waste water treatment plant | clay, synthetic liner, soils, vegetation | uses standpipes within landfill area, frequency unknown |
| SCA | South Carolina | 270 acres | not available | opal claystone | primary - clay<br>secondary - reinforced hypalon | primary - 5 feet<br>secondary - 30 mil | primary - $10^{-7}$ cm/sec.<br>secondary - not available | 3 cells | vitrified clay pipe, separate system for each cell | absorbed and re-landfilled | layers of soil, 30 mil hypalon, compacted clay of $10^{-8}$ cm/sec, soil and vegetation | monthly, 10 surface water, 8 ground water |
| DuPont | New Jersey | 15 acres/800,000 cu.yds./15 years | above ground only 66 feet | not available | primary - hypalon<br>secondary - hypalon protected by layers of sand and gravel | not available | not available | not available | 150 feet intervals | waste water treatment plant | 2 feet clay, 1 foot topsoil, side slopes 1-1/2 feet | upstream and downstream plus leak detector, frequency unknown |
| Gallenbach | Bavaria, West Germany | 17 ha/1.5 million cu.m/15-20 years | not available | clay and loam 8 to 18 m thick | natural clay loam | 40 cm minimum over natural clay floam of 8 to 18 m | $10^{-8}$m/sec. | 4 phases | 10 cm plastic | to retention tanks and waste water treatment plant | not available | stand pipes, frequency unknown |
| Bayer | Leverkusen, West Germany | 32 ha/6.3 million cu.m | above ground only 30 m | silty clay and sand lenses 3-4 m water table depth | primary - natural clay or compacted clay<br>secondary - polyethylene protected by 10 cm sand cushion | primary - 60 cm minimum<br>secondary - 2.7 mm | | not available | pipe in 30 cm gravel medium overlain by 70 cm subsoil | to waste water treatment plant | not available | borehole depths of 5 m plus peripheral ditches - frequency unknown |
| Kommunekemi | Nyborg, Denmark | 5 ha/300 tons per year 15-20 years | not available | salt water intrusion area | none | not available | not available | 3 cells | not available | not available | one cell covered with plaster membrane | 3 times per year |

# 6. RISK TO HEALTH AND THE ENVIRONMENT

## 6.1 Alternative Approaches

Risk is a recurrent area of concern touching on all aspects of the planning, design and operations of hazardous waste landfills. In this section, various options for the treatment of risk are considered. An approach is then presented which is intended to both minimize risk to human health and the environment and to recognize the constraints which exist in applying risk analysis to hazardous waste landfills.

Although it is generally recognized that risk to human health and the environment is of paramount concern in the planning, design and operation of hazardous waste landfills, the most appropriate approach to addressing risk is far from resolved. The level of precision at which risks should be addressed, and whether risks can or should be addressed implicitly or explicitly, remains a source of considerable controversy.

The approaches most frequently put forward include:

- zero risk;
- direct quantitative risk assessment;
- risk management;
- lists of considerations.

### a) Zero Risk

The belief that a hazardous waste project should be designed such that there is no risk to human health or the environment is a position often taken by groups that oppose such projects. Complete containment of wastes for specified periods of time, with a suitable range of active engineering measures, is not unrealistic. The extent of post-operations control, however, can never be absolute in perpetuity. The question which remains is then whether the risks which are entailed are socially acceptable.

### b) Direct Quantitative Risk Assessment

Direct quantitative risk assessment (see Figure 4) would ideally begin with a review of the properties of each substance. The probability of a release into the workplace or the environment would then be estimated. Every setting and every activity would be examined. Routes or pathways by which human populations would be exposed to substances of varying magnitudes would be explored. This analysis would involve the calculation of the probabilities of exposure for all the various pathways between events and people. Probabilities associated with various types of human health effects would then be calculated. Finally, the social acceptability of the estimated risks would be determined.

The application of the ideal procedure of risk assessment to hazardous waste landfills is illustrated in Table 5.

Proponents of a direct quantitative approach to risk assessment argue that it offers greater control and precision. Even though it is acknowledged that there are gaps in the "state-of-the-art", the quantitative approach, it is suggested, offers an ideal to strive for. In some areas, such as the direction and velocity of ground water flows in

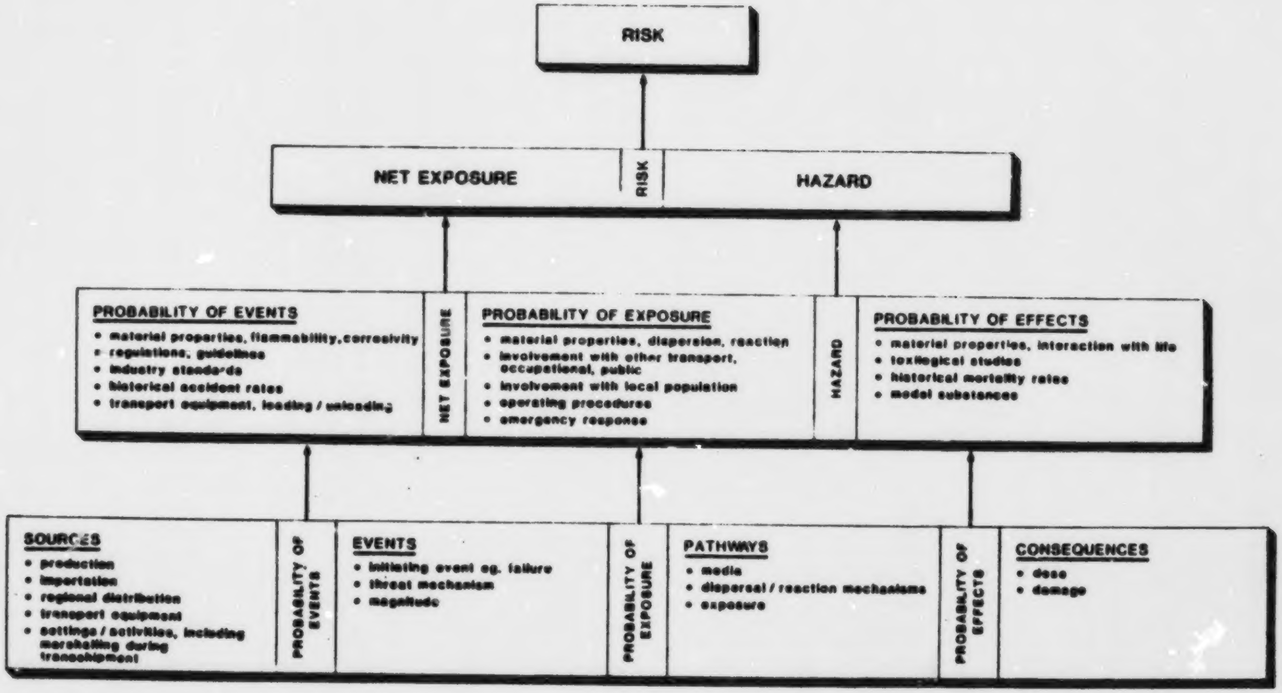

RISK
NET EXPOSURE
RISK
HAZARD
PROBABILITY OF EVENTS
• material properties, flammability, corrosivity
• regulations, guidelines
• industry standards
• historical accident rates
• transport equipment, loading / unloading
NET EXPOSURE
PROBABILITY OF EXPOSURE
• material properties, dispersion, reaction
• involvement with other transport, occupational, public
• involvement with local population
• operating procedures
• emergency response
HAZARD
PROBABILITY OF EFFECTS
• material properties, interaction with life
• toxilogical studies
• historical mortality rates
• model substances
SOURCES
• production
• importation
• regional distribution
• transport equipment
• settings / activities, including marshalling during transshipment
PROBABILITY OF EVENTS
EVENTS
• initiating event eg. failure
• threat mechanism
• magnitude
PROBABILITY OF EXPOSURE
PATHWAYS
• media
• dispersal / reaction mechanisms
• exposure
PROBABILITY OF EFFECTS
CONSEQUENCES
• dose
• damage

FIGURE 4
Risk Analysis

## TABLE 5
## APPLICATION OF QUANTITATIVE RISK ASSESSMENT TO HAZARDOUS WASTE LANDFILLS

| Ideal Risk Assessment Process | Application to Hazardous Waste Landfills |
|---|---|
| . Review of waste properties | . Analysis of site conditions, waste characteristics and facility design |
| . Analysis of probability of a release into the workplace or the environment | . Prediction of the rate and quality of leachate generation |
| . Analysis of routes or pathways by which human populations would be exposed | . Prediction of the rate and transport of constituents leached from the facility to the unsaturated zones, the saturated zone and subsurface soil<br>. Prediction of the rate and transport of gases and vapours which are released from the facility to the air |
| . Calculation of probabilities of exposure | . Prediction of the exposure of people, animals, plants, and other environmental components to released constituents |
| . Calculation of probabilities of human health effects | . Calculation of the total risk presented by the facility to human health and the environment |
| . Determination of risk acceptability | . Determination of the acceptability of the calculated risk |

relatively simple hydrogeological environments, predictions can be prepared with some confidence. The state-of-the-art with respect to risks during transportation is also relatively advanced. In addition, knowledge is growing rapidly concerning the relative effectiveness of various design measures and contingency planning procedures.

Opponents of the quantitative approach point to the large areas of uncertainty associated with the field, including the limited knowledge of: synergistic effects; dose-damage relationships; dispersion in complex environments; the effectiveness of various technologies and mitigative measures; or even the properties of the wastes themselves. Opponents further argue that quantitative risk analysis necessitates unsubstantiated value judgements, and inhibits further exploration by implying a greater level of precision than exists. They also point to the considerable time and resources required to generate numbers which, they consider, are of dubious value. Specific problems which have been identified with respect to the feasibility and desirability of proceeding with full quantitative risk assessment for hazardous waste landfills are noted in Table 6.

### c) Risk Management

Serious questions have been raised concerning the feasibility and desirability of undertaking risk assessment calculations. The alternative of managing risks without employing quantitative risk analysis takes a number of forms including: design and operating standards; containment standards; environmental performance standards; and technical standards.

## TABLE 6
## PROBLEMS WITH QUANTITATIVE RISK ASSESSMENT FOR HAZARDOUS WASTE LANDFILLS

- Effects of many constituents not well known.
- Synergistic and antagonistic effects of combinations of constituents are not well understood.
- Difficulties in confidently predicting the degree of containment, attenuation or mitigation of many management techniques.
- The difficulty in predicting the upward migration of volatile constituents through wastes.
- The fact that the modelling and monitoring of emissions from land disposal is still in its relative infancy.
- The general lack of long-term data as a basis for confidently predicting leachate or air emissions.
- The difficulty in predicting the decomposition of the by-products of decomposed hazardous wastes.
- Problems in the accuracy of predicting biological degradation.
- The general lack of extensive toxicological information concerning dose-damage relationships.

### i) Design and Operating Standards

Design and operating standards require the installation of specific equipment or the use of particular practices. An example is a liner specification such as 2 feet of clay with a permeability of $1 \times 10^{-7}$ cm/sec.

### ii) Technical Performance Standards

Technical performance standards establish an engineering objective and allow the permit applicant to develop a design or set of practices to achieve the objective. An example is a requirement to develop a runoff control system that can accommodate the runoff from a specified storm event (e.g. 24-hour, 25-year storm).

### iii) Containment Standards

A containment standard requires the permittee to keep waste or waste constituents within a certain area for a fixed period of time. Several variations of the containment approach are possible: the containment requirement may be limited to particular constituents; the boundaries for a containment zone could vary; and the time period for containment could vary.

### iv) Environmental Performance Standards

Environmental performance standards specify limits (usually numerical) on levels of contamination that may be tolerated in the environment. An example is a ground water quality standard for the ground water below the facility.

Each of these risk management approaches has advantages and disadvantages. Design and operations standards are specific and easy to implement. They may also, however, be arbitrary and inflexible, particularly in view of the rapidly changing technology in waste management.

Technical, containment and environmental performance standards offer greater flexibility. Although the standard is specified, the means of achieving that standard is left to the proponent. Performance standards are not always easy to develop or substantiate. Measurement of the results can also be difficult, particularly if the standards are imprecise.

Although the various approaches to risk management are valuable in reducing risk, particularly in combination, the questions which remain unanswered are: to what levels are risks reduced, and are the levels which remain more or less than society would accept if a full numerical risk assessment were undertaken?

### d) Lists of Considerations

The least precise approach to risk is simply listing a series of factors. This approach is usually suggested with respect to concerns which are highly site-specific or highly qualitative in nature. Such lists are clearly very flexible. At the same time they offer so much discretion that there is a considerable potential for abuse.

## 6.2 Recommended Approach

In addressing the question of risk, neither the full quantitative analysis of risk nor a complete reliance on lists of considerations would appear to offer the appropriate balance of control and flexibility for use in guidelines.

A range of risk management approaches would seem preferable as the basis for guidelines. Lists of considerations should only be employed in those instances where standards cannot be developed and substantiated.

This approach is consistent with that currently advocated by the U.S. Environmental Protection Agency which, "believes that technical performance standards in conjunction with environmental performance standards provide the right mix of certainty and flexibility to be implementable and to assure the proper emphasis on the environmental results of control measures". The EPA also, however, notes that "performance standards are often difficult to develop".

Table 7 identifies some general principles for addressing the issue of risk, recognizing the limits of the current knowledge base.

## TABLE 7
## COPING WITH RISK

### Explicit Approach

- Document rationale for simplifying assumptions
- Acknowledge value judgements and areas of uncertainty
- Substantiate standards
- Acknowledge limits of technology, methods and procedures

### Uncertainty

- Give preference to sites with simple environmental conditions
- Emphasize technologies with proven reliability
- Emphasize predictable design and management components
- Minimize potential for synergistic effects
- Assume wide margins of error
- Allow for a wide range of outcomes - sensitivity analysis
- Emphasize contingency and emergency planning

### Flexibility

- Be prepared to adapt to changing technologies, standards, procedures and knowledge

### Knowledge Base

- Monitor literature
- Provide for information exchange - agencies, organizations, interest groups
- Research particular problem areas - disseminate results
- Treat each project as a case study

## 7. AGENCY AND PUBLIC CONSULTATION

### 7.1 Alternative Approaches

The role of agencies and the public, in common with the treatment of risk, is a further area of concern which has implications for many of the planning, design and operating components of hazardous waste landfills. In this section, options for agency and public consultation are considered. A recommended approach is then presented. This approach is based on a recognition of the particular public issues and concerns which surround hazardous waste landfills.

As with risk assessment, two polar positions have emerged on the issue of public consultation. One position is that hazardous facility planning must be largely a closed process. Public fears, it is suggested, are so intense that local opposition (Not In My Back Yard) is inevitable. The need, it is pointed out, is simply too urgent. Opposition, it is argued, will die down once the facility is constructed and operating. It is also sometimes concluded that hazardous waste management facilities are simply too complex for the public to understand and to meaningfully contribute to their planning.

The alternative position is that the process of facility siting and planning must be an open process. Proponents of this position suggest that the public has a right to know about any project which is funded, or at least controlled by, public agencies, and which could potentially affect their lives. Advocates of an open process point to the potential costs and delays of introducing community concerns at the tail end of the approval process. They note the important technical and non-technical knowledge which organizations, groups and individuals can contribute to facility planning. They stress that an open planning process can ensure that the planning and design reflect community concerns and priorities. It can also provide, they point out, a basis for the resolution of conflicting perspectives or, at the very least, provide a means for facilitating community acceptance.

## 7.2 Recommended Approach

Although results to date do not provide a clear pattern, most of the points made by the proponents of a closed process do not appear to bear up well under close scrutiny. Public opposition may be inevitable but many of the public concerns are legitimate and can often either be allayed through information or resolved through negotiation and compensation. The record of closed procedures in expediting the construction of facilities has been far from uniformly successful. It could be argued that, if anything, a closed process intensifies opposition and ultimately, delays rather than facilitates approval. The public, moreover, does have a right to know. It has also been repeatedly demonstrated at public hearings that opposition groups, even with limited technical resources at their disposal, have a great deal of substance to contribute to the planning and operations of hazardous waste management facilities.

The issue, it is argued here, is not whether public participation should take place but rather what form of participation most directly responds to the concerns and priorities of both the proponent and of the various affected publics.

To develop an appropriate set of procedures for agency and public consultation it is, however, essential that the particular problems associated with the process of siting and operating hazardous waste landfills be reflected in the procedures employed (Table 8).

Table 9 contains some suggestions concerning ways of more effectively exchanging information, of facilitating agency and public involvement, and of resolving differences.

## TABLE 8

## MAJOR ISSUES AND CONCERNS FOR HAZARDOUS WASTE LANDFILLS

- Fears concerning risk to human health and the environment.
- Distrust concerning the adequacy of technology and contingency planning.
- Lack of faith in the ability of public agencies to regulate or enforce environmental requirements.
- Rumours and misconceptions are commonplace.
- Controversial nature of project means that media plays a central role in defining issues and shaping public attitudes.
- Danger of selling rather than explaining the project in the process of simplifying technical information.
- Multiplicity of parties directly and indirectly affected or interested; each with different concerns, values and resources.
- Process of involving affected publics complicated by large areas of uncertainty.
- Benefits (e.g. reduced illegal dumping, removal of wastes from unsafe storage sites) are dispersed over a wide geographic area. Risks and impacts are, however, highly concentrated in the immediate vicinity of the site and major access roads.
- Perception that waste generators should solve their own problems at source and not export wastes from their factories, etc.
- Need to separate facilities from areas of high population concentrations means facilities located in areas where only a small proportion of wastes generated; an inherent inequity in minds of affected residents.
- Concerns that social "stigma" will be attached to area; fear that facility will drive down property values and impair community image and character.
- Belief that once facility established, the area will progressively become a waste complex.
- Concerns regarding loss of on-site resources such as agricultural land, potential limitations on uses surrounding the site, the relative lack of local economic benefits and compensation and the potential burden on local services.

## TABLE 9
## SUGGESTIONS - AGENCY AND PUBLIC PARTICIPATION

### Information

- Adapt timing, content and scope of information to concerns and resources of groups and agencies.
- Consider implications of group and community characteristics for type, distribution and significance of risks and impacts.
- Ensure information readily understandable without being superficial or biased.
- Focus on community issues, concerns and misconceptions as they arise.
- Ensure full information on need, long-term planning, relationship to system, monitoring, contingency and after-use planning and regulation and enforcement procedures.
- Involve groups and organizations with specialist knowledge.

### Involvement

- Ensure public and agency participation an integral part of project planning from outset with input at all key decision points.
- Ensure responsive to all agency and group concerns and perceived risks.
- Provide technical and financial assistance as needed.
- Seek out and anticipate potential concerns and problem areas.
- Fully inform and involve media and elected representatives.
- Maintain involvement through closure and after-use planning and monitoring.

### Resolution

- Focus on critical problem areas.
- Negotiate as much of siting, design and operations of facility as possible.
- Emphasize mitigation of negative and enhancement of positive.
- Focus on means of compensation.
- Focus on qualitative concerns, e.g. community image - on an issue by issue basis.

# 8. SITE SUITABILITY

## 8.1 Alternative Approaches

The selection of a site which provides good natural attenuation and minimizes the potential for adverse community and environmental impacts, can greatly facilitate the design, construction and operations of a secure landfill. In this section, alternative approaches to site suitability analysis for a secure landfill are explored. The approach which is recommended, describes key site selection criteria, identifies their major interrelationships and indicates the points at which they should be introduced into the site selection process.

Unlike some of the other hazardous waste landfill components, alternative positions with respect to site suitability are not clearly defined.

The predominant treatment of site suitability in guidelines tends to take the form of lists of considerations. These lists vary considerably in the range of factors which they encompass. There is, however, some consensus that hydrogeological and surface water hydrology are especially important as they represent the primary pathways to the environment.

Lists of considerations provide a reasonable checklist of concerns and ensure sufficient flexibility to adjust criteria to changing geographic circumstances. The major difficulty associated with checklists is that they provide only limited guidance concerning the relative importance of different criteria, as well as when and how different criteria should be applied.

Although not reflected in existing provincial regulations or guidelines, a number of site selections for individual hazardous waste landfills have employed numerical weighting and ranking schemes as a basis for defining the importance of different factors. Such systems also simplify the process of combining criteria in the comparative evaluation of sites.

There are however, a number of serious difficulties associated with weighting and ranking systems. The process of ranking and weighting can be extremely arbitrary and inflexible. A single concern which is sufficiently serious to warrant rejection of a site can be averaged out. The process itself is often time consuming and costly, and may inhibit rather than enhance the identification of critical trade-offs and the documentation of the rationale for rejecting or accepting a given site.

## 8.2 Recommended Approach

In view of the limited guidance which lists of considerations provide, and the dangers and difficulties which tend to be associated with numerical weighting and ranking systems, an intermediate approach is considered more appropriate. With such an approach, in addition to listing considerations, the relative significance of different criteria, their major interrelationships and the manner of their application would be specified.

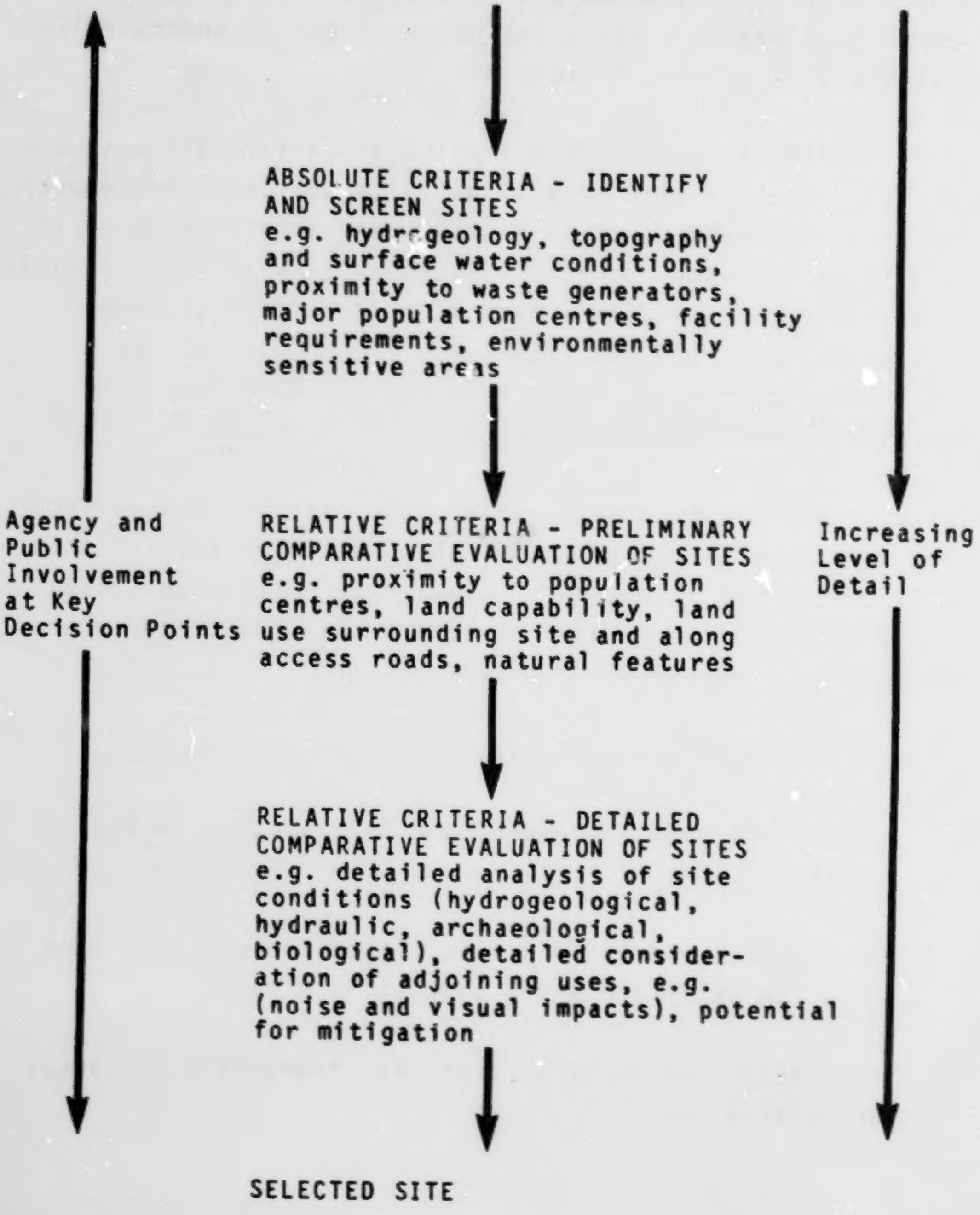
A large number of factors can be employed during site selection. They vary depending on both the stage in site selection and the type of area under consideration. Figures 5 and 6 illustrate how different criteria can be incorporated into the site selection process.

It is not the intent of this section to explore all possible considerations in site selection. Site selection procedures for hazardous waste facilities have been addressed in depth in a number of other sources (see Appendix N). A broad range of possible considerations have been identified as illustrated in Table 10. The importance of minimizing risk and achieving community acceptance is reflected in the criteria identified in Section 8.3.

Irrespective of which criteria are employed in an individual site selection, it is essential that the interrelationships among the criteria, and their cumulative impacts and risks be appreciated. It is also important that the criteria are employed in a manner which ensures that:

- the criteria are explicit;
- agency and public concerns are incorporated in the analysis;
- they illustrate the distribution of impacts over time, geographically and among population groups;
- they highlight critical problems, trade-offs and areas of uncertainty.

FIGURE 5
SITE SELECTION PROCESS



ABSOLUTE CRITERIA - IDENTIFY AND SCREEN SITES
e.g. hydrogeology, topography and surface water conditions, proximity to waste generators, major population centres, facility requirements, environmentally sensitive areas

RELATIVE CRITERIA - PRELIMINARY COMPARATIVE EVALUATION OF SITES
e.g. proximity to population centres, land capability, land use surrounding site and along access roads, natural features

RELATIVE CRITERIA - DETAILED COMPARATIVE EVALUATION OF SITES
e.g. detailed analysis of site conditions (hydrogeological, hydraulic, archaeological, biological), detailed consideration of adjoining uses, e.g. (noise and visual impacts), potential for mitigation

SELECTED SITE

Agency and Public Involvement at Key Decision Points
Increasing Level of Detail

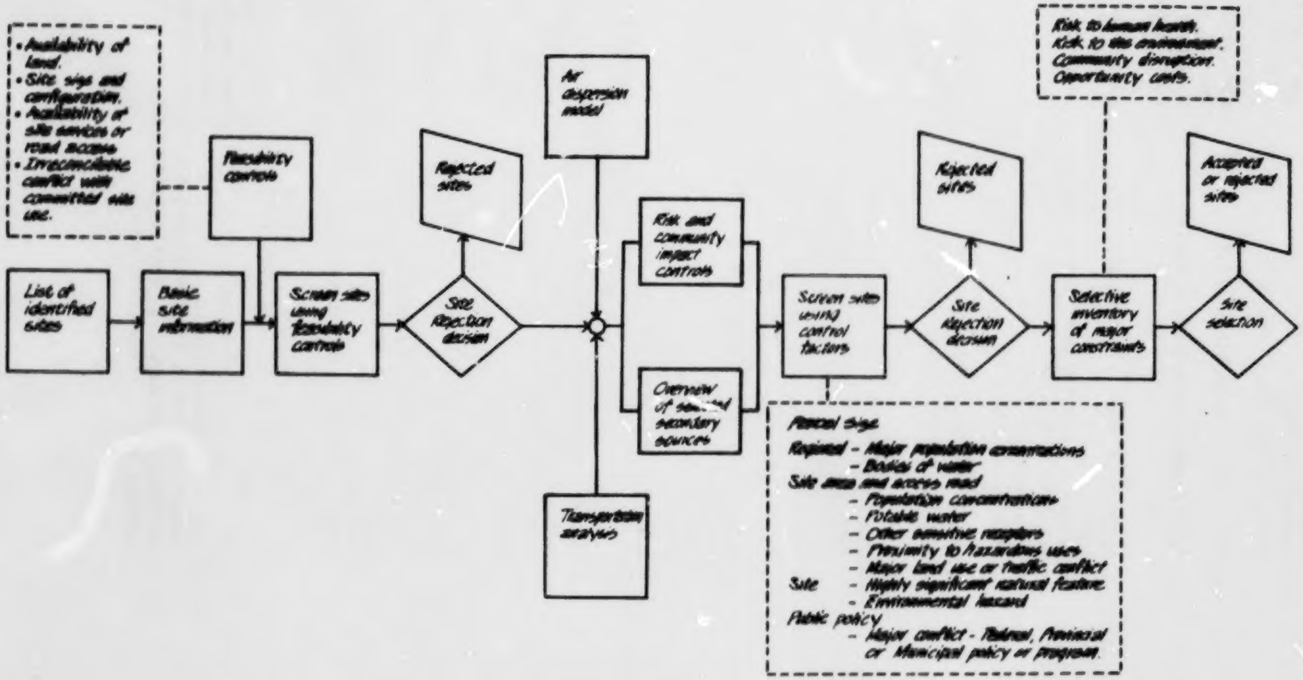

• Availability of land.
• Site size and configuration.
• Availability of site services or road access.
• Irreconcilable conflict with committed site use.
Feasibility controls
List of identified sites
Basic site information
Screen sites using feasibility controls
Site rejection decision
Rejected sites
Air dispersion model
Transportation analysis
Risk and community impact controls
Overview of selected secondary sources
Screen sites using control factors
Parcel size
Regional - Major population concentrations
- Bodies of water
Site area and access road
- Population concentrations
- Potable water
- Other sensitive receptors
- Proximity to hazardous uses
- Major land use or traffic conflict
Site - Highly significant natural feature
- Environmental hazard
Public policy
- Major conflict - Federal, Provincial or Municipal policy or program.
Site rejection decision
Rejected sites
Selective inventory of major constraints
Risk to human health.
Risk to the environment.
Community disruption.
Opportunity costs.
Site selection
Accepted or rejected sites

FIGURE 6
Example–Site Selection

## TABLE 10
## SITE SELECTION CRITERIA

| | Risk | Community Acceptance |
|---|---|---|
| **Facility Requirements** | | |
| . site size | . adequate for remedial actions (safety margins)<br>. adequate for future expansion | . adequate to prevent future land use conflict<br>. adequate to avoid noise, visual disruption |
| . proximity to waste generators | . minimizes transportation risks | . area generating waste bears impacts and risks |
| . site access and services | . facilitates contingency planning | . burden to community services and facilities |
| **Biophysical Conditions** | | |
| . hydrogeology | . hazards to site, e.g. seismic zones, faults<br>. pathways to environment for leachate migration<br>. simplicity of conditions<br>. natural attenuation | . ground water users<br>. public mistrust of design measures and operating procedures - assumption of release |
| . hydrology | . risks to site - flood plain, coastal hazard zones, washout | . surface water users<br>. flood probability - a difficult concept |
| . climate | . implications of climate to likelihood and severity of dispersion - precipitation, winds, evapotranspiration<br>. air dispersion characteristics | . sensitive uses exposed |
| . topography | . hazards to site - landslides, slippage<br>. runoff control | . role in visual and noise attenuation |
| . soils | . porosity and permeability | . capability for alternative resource uses |
| . biotic environment | . wetland ecosystems - ground and surface water connections<br>. bioaccumulation | . endangered or threatened species<br>. environmentally sensitive and significant areas<br>. use of vegetation to screen site and access roads |
| **Human Environment** | | |
| . site related | . population levels (existing, planned proposed)<br>. conduits or pipes (pathways)<br>. uses difficult to evacuate, e.g. hospitals, schools<br>. high intensity uses (temporary population concentrations)<br>. emergency back-up fire and police<br>. proximity to other hazardous uses | . historical, archaeological, cultural resources displaced and affected<br>. population and group characteristics - sensitivity and adaptability to change<br>. community image and character |
| . access roads | . distance<br>. road type and conditions<br>. traffic characteristics<br>. population levels and concentrations<br>. potential pathways e.g. proximity to surface water, rivers crossed | . interference with local traffic movements<br>. noise and visual intrusion<br>. sensitive uses |

A brief elaboration of the major areas of concerns identified in Table 10 is provided below. The major interrelationships among criteria have also been highlighted.

## 8.3 Major Areas of Concern and Interrelationships

### a) Hydrogeology

Hydrogeological considerations play a particularly significant role in the site selection process because, to a large extent, the technical success of the project in isolating hazardous wastes from the environment is largely tied to this criterion. The seepage of contaminated ground water from a landfill site represents one of the most likely escape pathways.

In common with the rest of the site selection process, hydrogeological criteria are applied in a staged manner from the initial broad screening considerations to site specific detail, sometimes requiring design modifications to enhance the positive aspects of a particular site and overcome the negative ones.

The following describes the staged application of hydrogeological considerations in the site selection process.

In the first stage of site selection in which very large areas are under consideration, the rejection of unsuitable sites tends to be based largely on topographic and regional geological considerations. Regional considerations which may preclude the successful implementation of a hazardous waste landfill are as follows:

- sites underlain by potable water aquifers;
- sites located in extensive zones of sand and gravel deposits;
- areas subjected to rapid erosion and/or inundation;
- sites susceptible to landslides;
- sites underlain by karstic limestone and dolomite deposits;
- hilly terrain, particularly adjacent to bodies of surface water;
- sites adjacent to active fault zones.

In addition to providing a basis for the rejection of sites in the early stages, regional considerations may also aid the investigator in selecting appropriate sites for further study. Hydrogeological conditions which are, in general, favourable include:

- areas where extensive clay deposits are found;
- areas remote from surface bodies of water;
- sites with generally flat topography;
- areas underlain by intrinsically impermeable rock at relatively shallow depth (shales, unfractured igneous rock).

Following the initial process of selecting a large number of possible sites for further consideration, more stringent criteria are applied for selecting sites for more detailed investigation. The criteria which tend to be most significant for the hydrogeological aspect of this selection are those features which promote the natural long-term containment of the waste. While the containment capabilities of the facility can be enhanced by passive engineered features, the degree of natural containment provided by the hydrogeological features must be favourable as a starting point for the development of the containment system.

In particular, those features which are generally accepted as being desirable in a waste disposal site are as follows:

1. low permeability materials
2. low natural hydraulic gradients
3. high capacity for adsorption of contaminants

In practice, deposits that will inhibit appreciable subsurface migration are generally clayey deposits of glacial origin. More permeable glacial deposits such as gravel, sand, or silt generally have a lower potential for containment. Bedrock in the near surface zone typically has fractures that provide unpredictable pathways for contaminant migration. Currently available technology is inadequate to provide accurate prediction of contaminant migration through fractured bedrock. Reliable assessment of the impact of a hazardous waste landfill facility in the near surface of fractured and weathered rock would be extremely difficult. In addition, these uncertainties pose problems with respect to monitoring of such facilities.

Although it is generally recognized that clayey deposits of glacial origin (clayey glacial till or glacialacustrine clay) have a greater potential for containment of contaminants, the capacity of these deposits to function in this respect is site specific. To a large extent the investigations which are necessary to select a particular site are aimed at resolving the site specific details. The geological environment in which the deposits were originally lain down can also produce local unfavourable occurrences such as sand lenses and stringers. The existence of such features along with their extent and location are a primary concern in the detailed investigation. Similarly, weathering of the desposits can result in secondary seepage pathways such as joints, fractures, or root holes.

### b) Other Physical and Biological Considerations in Site Selection

The potential for a release of contaminants into surface waters is an important consideration in site selection. Areas which should be avoided include flood plains, coastal high hazard areas and areas subject to washout. Consideration should be given to the effects of dams and to the probability and magnitude of extreme meteorological events.

As previously noted in Section 4, areas subject to high levels of precipitation tend to be less suitable. Areas of high net evaporation tend to be more suitable. Chemical reactions are inhibited by low temperatures although permafrost areas are not suitable for hazardous waste landfills. In addition, meso- and microclimates determine the site air dispersion characteristics both for fugitive emissions and major releases. Air dispersion models, using suitable climatological data, can establish distance thresholds for facility boundaries, population levels, surface water features and sensitive uses and resources. They can also assist in facility design and contingency planning.

In terms of the biological environment, sensitive natural areas should be avoided when identifying prospective sites and areas. Of particular importance is the potential for jeopardizing endangered or threatened species through the removal of their habitat, restriction of movement or migration and endangering the environment on or adjacent to the sites. In the comparative analysis of sites, relative differences in potential impacts on flora and fauna, on and adjacent to the site and along the primary access roads, should be explored.

At the detailed analysis stage, consideration should be given to the use of existing vegetation and other natural features to screen the site and access roads from adjoining areas. Natural buffer areas may be maintained or enhanced by planting.

The interrelationships among hydrological conditions, climate, topography, hydrogeological conditions and the biological environment should be carefully considered. Both direct and indirect impacts, i.e. through ground and surface water connections and air dispersion, should be considered.

### c) Community Considerations

Risk-related community considerations tend to fall into two categories: site related and access route-related. In view of the potential for accidental release, built-up areas and areas with high population levels should be avoided. The magnitude and distribution of existing and planned population levels, calculated on the basis of air dispersion, hydrogeological and hydrological analysis should be considered.

Particular note should be made of sensitive uses such as hospitals and schools where evacuation might pose a problem.

Conduits such as storm water pipelines which might serve as pathways by which the wastes could escape from the site should be taken into account.

The proximity of back-up fire and police protection in the event of an accidental release should be recognized in the analysis. The relative proximity to other hazardous uses which might contribute to a higher cumulative risk should also be considered.

The potential for an accidental release when hazardous wastes are being transported to or from the facility necessitates consideration of factors which might bear on the potential for an accident such as: type of access; traffic volumes; road conditions; the relative presence of dangerous intersections, curves, etc.; and the time of day of transport. As with the site-related considerations, population levels, population concentrations, and surface water considerations (proximity to lakes, watercourses traversed, etc.) are important concerns in site screening, comparison and selection. In the detailed comparative analysis of sites, the safety of the primary access roads and the relative difficulty in containing spills at sensitive locations such as bridges should be considered.

In addition to risk-related factors, there are a number of other concerns which influence community acceptance including: effects on historical, cultural or archaeological resources; conflicts with local land uses; conflicts with local traffic, e.g. school buses, farm vehicle movements; impacts on utilities; and noise and visual intrusion.

Most of the potential problems cited above can be prevented or mitigated through site selection and design. A much more difficult issue is the question of impact on community character and image. Commonly cited concerns are the potential for property value depreciation and the creation of an image for the community which makes it less attractive as a place to live or establish a business. To some extent, this problem will exist for all potential sites. However, through the course of evaluating local community characteristics and concerns, it may become evident that it will be easier to satisfy the concerns of the residents and businesses in the vicinity of one site than another. It may also become evident that the establishment of the facility at one site will be more compatible with the character of that area than with other sites.

### d) Facility Requirements

In many instances, prospective sites and areas can be eliminated from further consideration because they fail to meet such basic facility requirements as: site size (recognizing buffer requirements, local conditions and expansion potential); proximity to waste generators (remote sites increase transportation risks and costs); and proximity to all-weather roads and services. Some degree of interpretation will be required to address these concerns as in some instances, they will represent comparative criteria (as components of costs), rather than screening criteria.

## 9. WASTES FOR LANDFILLING

### 9.1 Criteria for Hazardous Waste Landfilling

It has been stated previously as a planning principle that landfilling of hazardous wastes should be used as a "last resort", after consideration of other options including waste reduction, recovery or reuse; destruction; or treatment. Nevertheless, a broad range of wastes currently remains under consideration for landfill, because of the limitations of the first group of options and the very limited capacity in Canada of treatment and destruction facilities.

Given that the primary objective of the guidelines would be to minimize risk from land disposal of such hazardous wastes, important questions to be resolved are: which wastes are suitable for landfill and in what form? If the risk of land disposal is considered unacceptable for particular wastes, and no suitable treatment or destruction facility exists currently in Canada, then interim storage may be a preferred option. This risk must be assessed in the context of the uncertainties associated with land disposal technology in order to arrive at an environmentally sound approach. Uncertainties include the long-term performance of landfill liners and caps, the behaviour of hazardous constituents in the subsurface, and their health and environmental effects.

Although there is no generally accepted strategy for defining wastes suitability, several jurisdictions have attempted to quantify the factors involved in developing regulations to restrict landfilling of particular types of wastes. A number of these regulations were referred to in Section 5, and details of the proposed regulatory approaches for the States of California, New York and Minnesota are provided in Appendix H.

Based on a review of such approaches, the principal factors considered in restricting particular wastes and the rationale for each factor are summarized in Table 11.

### TABLE 11
### FACTORS FOR ASSESSING WASTE SUITABILITY FOR SECURE LANDFILLS

| Factor | Rationale |
|---|---|
| . Toxicity | . Human health and environmental effects. |
| . Persistence in the environment | . Potential for human and environmental exposure increased by slow degradation. |
| . Mobility (including leachability, soil migration) | . Increased potential for transport to ground and surface water. |
| . Reactivity | |
| - Ignitable | . Potential for fire or explosion. |
| - Explosive (including pyrophoric, shock sensitive) | . Potential for fire or explosion. |
| - Corrosive | . Potential for damaging liner or dissolving other wastes and increasing their mobility. |
| - Ability to bioaccumulate | . Potential to concentrate in the food chain. |
| - Incompatible | . Potential for dangerous reactions with other wastes. |
| . Volatility | . Increased potential for transport to atmosphere. |
| . Free liquid content | . Potential for dissolving other wastes and increasing their mobility; possible deterioration of landfill structural integrity; increased leachate generation. |
| . Void space | . Potential to cause subsidence and damage structural integrity of landfills. |

Examination of the factors identified for waste suitability suggests that the guidelines would consist of two basic types: those where existing information provides a clear direction or there is a consensus of opinion in the technical community; and those where different approaches are being considered and it is difficult to provide quantitative guidance without further more detailed study. There is, for example, a clear consensus on the prohibition of ignitable wastes for landfills because of their inherent fire risk. There is no such agreement on quantitative considerations for waste toxicity because of the complexity of the factors involved.

These differences are reflected below in the description of waste categories for which restrictions are proposed. In reviewing this description, it is important to realize that wastes which are unsuitable for secure landfill may often be rendered suitable by appropriate pretreatment measures.

## 9.2 Restricted Waste Categories

### a) Liquid Wastes

Regulations proposed by the U.S. Environmental Protection Agency allow the disposal of bulk liquids in landfills, as long as a liner and collection system is installed. The rationale for accepting bulk liquids is that these liquids or the resulting leachate will be removed from the landfill during its operating life. However, there are disadvantages to this approach in that the volume of liquid to be handled is increased. It has also been suggested that liquid drainage may occur over an extended period causing subsidence and the loss of integrity of the final cover.

The rationale for landfilling of bulk liquid wastes would appear to be based on expediency rather than representing a long-term safe solution. Such liquids would drain through the landfill and become leachate. From the standpoint of a long-term mass balance, this leachate would require treatment and removal off-site.

Accordingly, bulk liquid disposal has been restricted or prohibited by several U.S. states and in other jurisdictions. Compromise approaches have suggested using a limitation of total liquid input to the landfill, based on site-specific considerations of infiltration and landfill design. It is considered here that such approaches are unnecessarily complicated by the uncertainties in the calculation of water balances, and that the Canadian guidelines should therefore prohibit the direct landfilling of bulk liquids. Implicit in the adoption of such a restriction is that other technologies, such as fixation or solidification, will be required and provided to permit the ultimate landfilling of liquid wastes. Alternatively, other physical-chemical treatment facilities will be required to treat such wastes, i.e. to ensure a safe liquid effluent for discharge and sludges suitable for landfilling.

Liquid wastes in containers pose essentially similar problems, since containers will ultimately deteriorate and release their contents. Whether this deterioration occurs during the operating life, post-closure care period, or thereafter, it may cause the same problems of subsidence and leachate generation.

Against this must be balanced the consideration that small generators of hazardous waste will inevitably use containers such as steel drums for collecting their liquid wastes, and that prohibition of landfilling containerized liquids would require either solidifying the liquid in the drum or a liquid transfer step for some form of processing. It is arguable that the transfer operation introduces the risk of spillage and/or worker exposure. It is considered, however, that this risk is of short-term duration and of lesser importance than the threat to the structural integrity of the landfill. Liquids in containers should, therefore, be included in the liquids ban.

For practical purposes, there are certain exceptions which are suggested:

- containers that are very small such as ampoules;
- containers designed to hold free liquids for use other than storage, e.g. batteries;
- small containers such as laboratory chemicals in overpacked drums, commonly known as lab packs.

These exceptions should be subject to the limitations on waste composition, discussed in item d).

### b) Containers

Concern has been expressed about the landfilling of containers, both empty and as receptacles for wastes, because of their poor load-bearing capacity. This concern is clearly warranted in the case of contaminated "empty" containers, where spaces within containers such as steel drums will ultimately cause settlement as the drums deteriorate. Empty containers should, therefore, be crushed, shredded or similarly reduced in volume to the maximum practical extent before landfilling.

For containers used as waste receptacles, there are two separate situations: containers of liquids which would be prohibited as discussed in item (a), and containers of solids and/or sludges. With solids and sludges, the concern is one of ensuring that the containers are full, and do not contain significant spaces. In the United States, this requirement is quantified as "90 per cent full", which means that there could be about 10 cm of space in the typical 45 gallon drum. There is no rigorous data to support this limit, and it has been proposed on a judgemental basis as the best approach achievable in practice. In the absence of a more rigorously derived limit, it is proposed here as the basis for discussion.

c) Reactive Wastes

Under the Canadian Task Force definitions, reactive wastes include those wastes which are explosive, ignitable including pyrophoric), corrosive or interactive. Given the breadth of the definition, it is appropriate to consider the suitability of each of the four classes individually:

Explosive wastes are clearly not suitable for landfilling as a result of their potential for violent reaction.

Ignitable wastes are not suitable for landfilling because of the fire risk. In the absence of a quantitative definition of "ignitable" liquids, by the Task Force, the U.S. Environmental Protection Agency's definition of wastes having a flash point of less than 60°C is proposed for discussion purposes. The prohibition of liquid disposal in secure landfills would, to a large extent, eliminate the acceptance of ignitable liquids such as solvents.

Corrosive wastes are of concern for secure landfill because of the potential for liner deterioration and dissolution of other materials. In the absence of a quantitative definition of "corrosive" by the Task Force, the U.S. Environmental Protection Agency's definition of wastes having pH <2 or >12.5 is proposed for discussion purposes. The prohibition of liquids from secure landfills would, to a large extent, eliminate the acceptance of corrosive wastes such as acids, alkalis, and solvents.

Interactive wastes are defined as those which can bioaccumulate or form compounds which are hazardous. On the basis of this definition, it is considered that these wastes should be prohibited from secure landfills. This limitation would effectively eliminate bioaccumulative materials such as PCBs and many pesticides; as well as materials such as cyanides and sulphides, which have the potential to generate toxic gaseous reaction products as a result of pH changes.

An unresolved question would be that of concentrations to be used for defining significant quantities of these constituents in a waste. The reader is referred to Appendix H, which describes approaches under consideration by other jurisdictions.

### d) Incompatible Wastes

Strictly speaking, incompatible wastes form a sub-part of the class defined as "interactive" wastes, but are treated separately here, since incompatibility among wastes is often considered an operational concern rather than an absolute suitability criterion. Such wastes, when placed in contact with each other, cause hazardous conditions such as fires, explosions or generate toxic products. If these wastes are acceptable for landfilling on the basis of all other suitability criteria, then it has been suggested that they be accepted provided they are placed in separate cells within the landfill.

This consideration is intended to apply primarily to landfills accepting liquid wastes, where free liquids make for greater mobility of wastes. Given the proposal in item a) that free liquids not be placed in secure landfills, the use of segregated cells for separating incompatible wastes becomes redundant since such wastes would already have been pretreated to render them compatible.

This conclusion is, however, not intended to suggest that landfill cells be excluded from the process of landfill construction.

The use of separate cells is a valid approach to phasing site operations (see Section 10), and may also have application as a means of segregating particular waste types for operational convenience or long-term recovery potential. Rather, it is intended to demonstrate that pretreatment requirements or restrictions on waste suitable for landfilling will eliminate incompatibility among wastes placed in the landfill. Prior to this, the incompatibility concern arises in the handling and pretreatment steps that may occur prior to landfilling. For the purposes of waste handling and pretreatment, a summary is therefore provided in Appendix I of incompatible chemical groups likely to be encountered in hazardous wastes.

### e) Sludges

In item a), it was suggested that liquids should be prohibited from secure landfills, primarily because of increased leachate generation and potential deterioration of the structural integrity of the fill. To some extent, the same concern may apply to sludges depending upon their moisture content and physical characteristics. One approach to resolving this problem is to require all materials deposited in the landfill to be pretreated or have existing properties such that they possess a minimum structural strength. This type of concept has been adopted by the nuclear industry in the United States, where the U.S. Nuclear Regulatory Commission requires that low-level radioactive wastes placed in landfills should be capable of maintaining their form and physical dimensions within 5 per cent under expected disposal conditions of compressive load of 50 psi. The approach has also been proposed for hazardous waste landfills in New York.

Such a scheme may, however, be difficult to implement in practice. It is also not clear how effective landfill equipment may be in the compacting of sludges and in improving their structural strength. It is, however, recommended that sludges deposited in a secure landfill have sufficient load-bearing capacity to allow landfill compactors to be used without the material collapsing.

### f) Other Waste Restrictions

Factors for waste restrictions not explicitly described in items a) to e) include toxicity, persistence in the environment, mobility and volatility. While it is generally agreed that disposal of highly toxic, highly persistent, highly mobile or highly volatile wastes is to be avoided, there is some considerable difficulty in defining the thresholds for acceptability. This difficulty stems from the uncertainty in defining critical environmental parameters relating to transport, fate and health effects for hazardous waste constituents. In particular, there is a need for a better understanding of the leachability of hazardous constituents from landfills, the removal mechanisms and half lives for these constituents in ground water, surface water, and the atmosphere, as well as human health and environmental effects, particularly long-term effects.

In other jurisdictions (see Appendix H), in spite of these uncertainties, programs have been developed to identify wastes unsuitable for landfilling, using a variety of approaches such as leachability criteria related to drinking water standards or toxicity testing (animal exposures), listings of metals, carcinogens and highly toxic substances. Different jurisdictions have proposed different concentration criteria and testing methods, and it is not considered that any one system would necessarily fulfill the needs of the Canadian hazardous waste situation. It is, however, recommended that such a system be developed based om similar considerations, but with specific reference to the hazardous wastes generated in Canada and in the context of existing Canadian standards, e.g. for water quality.

In the meantime, it is worth pointing out that, in the absence of these criteria, a significant proportion of potentially unsuitable wastes may be excluded by other considerations outlined in items a) to e). For example, the exclusion of liquids and reactive wastes would prohibit many volatile solvent wastes, persistent materials that are also bioaccumulative such as PCBs and some pesticides, strong acids and alkalis, cyanides, sulphides, etc. In some cases, these wastes can be rendered suitable for landfilling by use of appropriate pretreatment techniques.

## 9.3 Pretreatment Options

For those wastes that are excluded from secure landfills because of their chemical or physical characteristics, there are pretreatment techniques by which these characteristics may be mitigated or eliminated depending on the nature of the waste. These techniques can be broadly divided into physical and chemical processes. The more common processes used are listed below:

Physical Processes:

- Crushing, shredding containers
- Topping up containers or transfer for bulk handling
- Stabilization to improve load-bearing capacity, e.g. addition of absorbents
- Dewatering e.g. filtration, sedimentation, centrifugation, etc.

Chemical Processes:

- Detoxification, e.g. cyanide treatment
- Neutralization e.g. acids, alkalis
- Precipitation, e.g. metal hydroxides
- Oxidation/reduction, e.g. cyanide oxidation, chromium (vi) reduction
- Chemical solidification/fixation

In some cases, the separation of physical from chemical processes is not well defined. For example, the use of fly ash and/or cement kiln dust for treatment of inorganic liquid wastes has been variously classified as stabilization and chemical fixation. In reality, there are a mixture of physico-chemical reactions involved from absorption to adsorption, neutralization and precipitation, dependent upon the type of waste.

In practice, a combination of techniques may be used to achieve the desired pretreatment. For example, a metal/cyanide sludge might first be treated to oxidize the cyanide and the resulting sludge then dewatered prior to secure landfill. Alternatively, a mixed metal sludge containing chromium (vi) could be treated with pickle liquor (ferrous sulphate in acid solution) to reduce the chromium (vi) to chromium (iii) and then solidified. Solidification processes, in particular, are considered an important method of extending the flexibility of secure landfill. Many of these processes are proprietary, but can generally be categorized as follows:

- cement-based
- lime-based
- thermoplastic-based
- organic polymer-based
- surface encapsulation.

A short description of each process is presented in Appendix J. The processes are designed to convert liquid wastes into a solid matrix having adequate structural integrity for landfilling, and at the same time, a low leachability. Various leach tests have been proposed for testing the adequacy of the solidified material's leachability involving basically one of two approaches: a shake test or a column test. Choice of solvent, test period, sample preparation and evaluation criteria are still a matter of controversy. The so-called E.P. (Extraction Procedure) Toxicity Test proposed by the U.S. Environmental Protection Agency is described in Appendix K.

## 10. DESIGN AND CONSTRUCTION

### 10.1 Introduction

In Section 3, a basic outline of the secure landfill concept was presented. In this section, a framework is presented for the development of guidelines for the design and construction of secure landfill facilities for hazardous wastes. Options for each major component of the landfill design are discussed and a preferred option identified wherever possible.

A schematic layout for a secure landfill facility is shown in Figure 7 to assist in the discussion presented in this section.

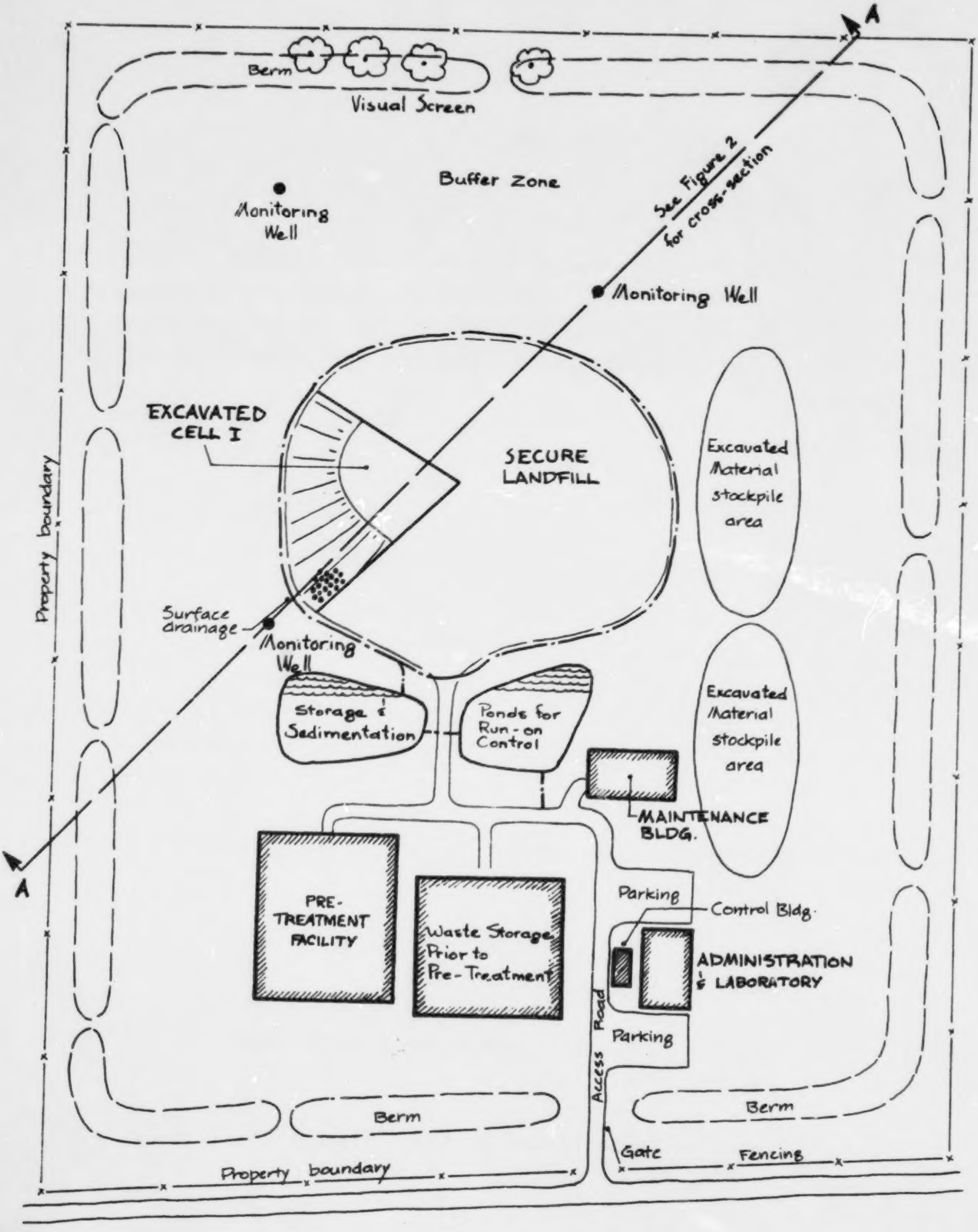
A more detailed discussion of facility design and operating technologies, and methods for evaluating performance of designs, is provided in a series of technical resource documents prepared by the U.S. Environmental Protection Agency. These documents include:

1. Evaluating Cover Systems for Solid and Hazardous Wastes (SW-867, PB 81-166-140).

2. Hydrologic Simulation in Solid Waste Disposal Sites (SW-868, PB-81-166-332).

3. Landfill and Surface Impoundment Performance Evaluation (SW-869, PB-81-166-357).

4. Lining of Waste Impoundment and Disposal Facilities (SW-870, PB-81-166-365).


A
Berm
Visual Screen
Buffer Zone
Monitoring Well
See Figure 2 for cross-section
Monitoring Well
EXCAVATED CELL I
SECURE LANDFILL
Excavated Material stockpile area
Property boundary
Surface drainage
Monitoring Well
Storage & Sedimentation
Ponds for Run-on Control
Excavated Material stockpile area
MAINTENANCE BLDG.
A
PRE-TREATMENT FACILITY
Waste Storage Prior to Pre-Treatment
Parking
Control Bldg.
ADMINISTRATION & LABORATORY
Access Road
Parking
Berm
Berm
Gate
Fencing
Property boundary

Typical Secure Landfill Facility
Figure 7

5. Management of Hazardous Waste Leachate (SW-871, PB-81-189-359).

6. Guide to the Disposal of Chemically Stabilized and Solidified Waste (SW-872, PB-81-181-505).

A further document will soon be available dealing with design specifications for the most important performance requirements, e.g. liners and caps.

7. Landfill Design - Liner Systems and Final Cover.

As with the design of any facility, the intended operation must be reflected in the design. This is of particular importance with a secure landfill where the initial construction generally will be limited to that required for the initial operation. Subsequent operating phases including closure and post-closure, will require construction at later dates. Thus to ensure that the initial design is effective and compatible, and consistent with longer-term requirements, it is suggested that a design and operations report for the secure landfill facility be a mandatory requirement prior to the preparation of detailed drawings and specifications for initial construction. This report would present the key design data and criteria, and include the overall design for the long-term development and operation of the site.

## 10.2 Liners

### a) Materials

As noted previously, the objective of a secure landfill is the containment of hazardous materials. Most soils, in their natural condition, do not offer sufficient certainty in achieving containment. Soils of low permeability may appear attractive in their natural condition. However, in clayey deposits of low permeability in Canada, the maximum depth of the zone of active weathering is within about 7 or 8 m of ground surface. Within this weathered zone, liquids will move according to the laws of ground water flow. The water table in such low permeability, clayey deposits will be within the weathered zone. Below the water table, molecular diffusion is the principal transport mechanism and is an extremely slow process.

Thus the location of a secure landfill in the zone of weathering in such clays requires careful design to prevent the migration of contaminants. In effect, a barrier, by means of a liner, is required to stop the flow into the weathered zone. Similarly, the location of a secure landfill in more permeable soil formations requires the use of a liner to prevent leachate migration. The liner may be constructed of in-situ or imported natural clay material, reworked by compaction equipment to give an acceptable permeability and thickness. Alternatively the design may incorporate one or more of a wide variety of other liners which include:

- admixed materials
- polymeric membranes
- sprayed-on liners
- soil sealants
- chemisorptive materials.

Information regarding liners, liner types, design criteria, performance evaluation and liner integrity under various conditions is extensively documented in the foregoing E.P.A.

References 3 and 4. It would seem, however, that the state-of-the-art in liner development, along with site- and waste-specific requirements in liner selection are such that no single liner type is appropriate for all cases.

Numerous jurisdictions have established liner requirements (as discussed in Section 5), but no general consensus regarding type has been reached. In California, for example, sites must be situated in naturally occurring clay materials. Although some imported clays may be used to supplement the in-situ conditions, artificial membranes are prohibited. At the same time, the U.S. Environmental Protection Agency has proposed regulations that would essentially prohibit the use of clay liners because of fluid penetration into the liner. In Nova Scotia, guidelines permit both clay and membrane liners. In Quebec, only clay liners are referred to in the Provincial guidelines.

While there is a lack of consensus regarding a single preferred liner type, it appears that in most applications the choice will be either clay or polymeric membrane, or a combination of the two.

The case for clay liners can be made on the basis of the relative ease of placement, long term integrity and reliability and effectiveness. The effect of leachate on soil permeability is the essential property which has to be considered. To date testing of clay liners using concentrated chemicals has indicated some increase in permeability for certain organics and inorganics but their effects at concentrations likely to be encountered in leachate remain questionable. Ideally permeability tests should be conducted on the liner material using liquid composition similar to that expected in the leachate.

The behaviour of a clay liner in limiting migration of liquid from the landfill can be considered in two phases. Initially, the clay liner will be unsaturated. With a small head of leachate on the liner, the clay will eventually become fully saturated. Subsequent to saturating the liner, leachate will penetrate and appear outside the liner. The time to saturate the liner may be approximated using a diffusion approach. Typical estimated times for saturation using a linearized diffusivity constant of $10^{-5}$ $cm^2$/sec are about 10 years for a 0.6 metre thickness and about a 100 years for a 2 metre thickness. Once the leachate has penetrated the liner a potential exists for contamination of the subsurface soil.

In summary, although it is reasonable to assume that an appropriately selected and properly placed clay liner will retain its integrity indefinitely, saturation of the liner will eventually occur. Subsequently, the rate of leachate flow through the liner will be a function of the head on the liner and the permeability of the liner and the sub-surface soil. Permeability values for natural glacial till may range from $10^{-4}$ to $10^{-10}$ cm/sec and from $10^{-7}$ to $10^{-10}$ cm/sec for unweathered marine clays. A value of $10^{-7}$ cm/sec or or $10^{-8}$ cm/sec would be typical for a well compacted clay liner and values as low as 5 x 10-9 cm/sec are not unreasonable. Thus the rate of flow of leachate via a clay liner into a sub-surface clay would be extremely slow. In clays of very low permeability, contaminant flux by molecular diffusion would also need consideration. This process could in fact transport chemical contaminants at a faster rate than would be indicated simply by ground water flow considerations in clays of very low permeability. Molecular diffusion could account for contaminant plume advance rates of 0.1 cm to 1 cm per year, and thus is still an extremely slow transport process.

Based on engineering, environmental and economic criteria, it should be determined whether the native soil present at a site can be used to produce an effective liner of the desired permeability. For the use of native or imported soils to be satisfactory as liners, a basic requirement is a relatively large proportion of fines in the soil, i.e. particle size less than 2 um. Information provided in the foregoing EPA reference 4 suggest that the minimum amount of clay size particles required in soil to yield a good soil liner is 25 to 28 per cent by weight.

Should soil liners not be feasible, there are a large number of synthetic membranes available, of which the most commonly used as liners are:

- Polyvinyl chloride (PVC)
- Chlorosulphonated polyethylene (CSPE)
- Chlorinated polyethylene (CPE)
- Butyl rubber
- Ethylene propylene rubber (EPDM)
- Neoprene
- High density polyethylene (HDPE)
- Low density polyethylene (LDPE)

The thickness of polymeric membranes for liners ranges from 20 to 120 mils, with most produced in the 20-60 mil range. A thickness of 30 mil is commonly used for liners, and is generally accepted as the minimum thickness appropriate. A synopsis of the composition, general properties and characteristics, general use, and specific use in liners is provided for each polymer type in Appendix L.

The movement of leachate via a synthetic membrane liner is by molecular diffusion. Synthetic liners are formulated to be impervious, and for practical purposes can be considered as such. A permeability coefficient of approximately $10^{-12}$ cm/sec is typical. The principal concern with synthetic membrane liners is their structural vulnerability and effective life when exposed to leachate. While extensive testing is ongoing in the United States and elsewhere, manufacturers will generally estimate the effective life for a synthetic liner at no more than 20 years.

In practice it is possible that the polymeric membrane may last considerably longer, and proponents of the use of membrane liners argue that with a properly operated leachate collection system, the membrane can achieve essentially 100 per cent collection and containment efficiency over its effective life.

Notwithstanding the general preference expressed here for liners constructed from soils and clays or polymeric membranes, the ultimate selection of liner material will require a detailed consideration of:

- compatibility and durability of the liner in the presence of the waste and waste by-products e.g. characteristics of the leachate to be contained;
- permeability of the liner material (i.e. the integrity of the liner) to contain wastes and leachate over the long-term;
- liner reliability and risk of failure;
- ease of installation, quality control, operation and maintenance.

### b) Design

There are various design options for liners with which some limited experience has been obtained, both for clay liners and for polymeric membranes. Some examples of these designs are described in Section 5. In summary, they employ three basic liner design options:

- the use of native clay soils as the protective liner;
- the use of imported clay soils or a polymeric membrane to provide a single liner; and
- the use of native soils/imported soils and/or polymeric membranes to provide a double liner.

The last option merits consideration. The double liner may consist of a composite of soils or polymeric membranes, or both liners may be of the same material. Between the liners is placed a drainage layer, which acts as a leak detection system, providing an additional level of monitoring of the site's integrity. Otherwise, the same considerations apply to the double liner as to the conventional single liner.

In selecting the appropriate liner design, the choice of liner type cannot be divorced from the effectiveness of the leachate collection system, the operating life of the landfill, the effectiveness of the ultimate landfill cover, the post-closure operation, and the subsurface conditions. For example, a landfill is assumed to have an active operating life of 10 years and is capped at that time. Prior to capping, the leachate collection system works effectively and essentially removes all leachate. In such a situation a membrane liner may be reasonably expected to contain the leachate and prevent migration. If it is further assumed that the landfill cap minimizes infiltration into the landfill and that the leachate system is operated periodically for another 10 years to remove this small amount of leachate, containment of leachate will still be achieved provided that the membrane retains its integrity. Failure of the membrane at this time could, however, present serious problems if the leachate is still shown to be seriously contaminated and the area is characterized by permeable subsoils. In this event, sustained operation of the leachate collection system would minimize the potential migration of contaminants until remedial works could be implemented under a contingency plan.

From the standpoint of employing the safest possible technology, the foregoing example illustrates the benefit of using a clay liner which would likely retain its integrity indefinitely. The safest technology, however would be the use of a double liner system, i.e. a synthetic membrane, to provide essentially complete containment during its effective life, in conjunction with a clay liner to provide a high level of integrity and assurance indefinitely. The use of a double liner where the two barriers are constructed of different materials is particularly attractive in that the failure mechanism affecting one liner is unlikely to affect the other in the same way.

The need for this high level of protection should be determined on the basis of the risk posed by liner failure. The principal factors to be considered should include the degree of hazard of the landfilled wastes; the permeability of the native soils; and ground water use in the vicinity of the site. In essence, the level of protection that the liner provides should be a function of individual waste and site characteristics.

### c) Installation

Having selected an appropriate liner design, the proper installation technique is an aspect critical to the satisfactory performance of the secure landfill. Detailed design specifications should be prepared and adhered to with special attention to quality control throughout the installation process, and to subgrade preparation particularly for polymeric membranes. A detailed discussion of construction methods is provided in the foregoing Reference 3. Some key considerations are described below.

For clay liners, it is important that the design specify the degree of compaction required (at a given moisture content) to achieve the desired permeability. The requirement for strength is secondary, but should be considered for embankments and dykes. The most important parameters to be controlled are liner thickness, soil moisture, compaction energy and lift height (the depth of the unit layer to be compacted at one time). Lift height is commonly in the order of 100 mm to 300 mm. The installation and compaction procedures should follow generally accepted geotechnical engineering practices, and should include a quality control program to ensure the design specifications are met. Visual inspections and field measurements of clay moisture content and density should be included in the quality control program. Consideration should also be given to adverse weather conditions, and to the resulting need for construction in a number of phases.

For polymeric membrane liners, the nature of the materials varies considerably, and in many cases, specific installation procedures are recommended by the manufacturer. Common to all membrane liners, are the general considerations regarding subgrade preparation. The subgrade provides support for the liner. The stability and integrity of the subgrade is therefore critical to the proper functioning of the liner. Subgrades should be smooth, preferably mechanically rolled and free of sharp rocks or vegetation that could cause punctures.

Weather conditions are an important factor, since wet conditions or low temperatures may adversely affect the quality of field seaming. Most material manufacturers recommend that seaming cease when ambient temperatures drop below 60°F.

Various liner protection measures should be included in the installation process:

- soil cover should be placed on top of the liner to protect against damage by weather conditions or equipment;

- gas vents should be included if gas generation is anticipated beneath the liner;

- if the seasonal ground water table is higher than the liner, a drain should be installed to relieve the hydrostatic head pressure.

As with clay liners, a quality control program should be included. Particular attention should be paid to field or laboratory testing of field seams, and to sealing around penetrations in the liners by pipes and other structures.

## 10.3 Leachate Collection and Removal System

Accompanying the liners is the general requirement for collection of the leachate. The system usually consists of perforated collection pipes bedded and backfilled with a free-draining coarse granular material such as crushed rock or gravel. The leachate collectors are located at the base of the landfill immediately above the liner. The collectors may have individual surrounds of free-draining material, or be placed in a drainage layer covering the entire liner.

The system drains towards a sump or a series of sumps and is pumped out for treatment and disposal. In some secure landfill designs featuring a double liner system, provision for a double collection system is made. In all cases, manholes and clean-outs should be provided for proper operation and maintenance.

Provision for a hydraulically sound leachate collection system should be a mandatory requirement for all secure landfills where leachate will be generated.

Two key elements in the appropriate hydraulic design of the leachate collection and removal systems are a quantitative asessment of the volume of leachate to be generated and the head of leachate that can be tolerated on the landfill liner. As stated previously, the head of leachate along with liner permeability and thickness will control the potential for movement of leachate through a clay liner.

### (a) Leachate Volume

The leachate volume produced by a secure landfill will consist of that volume of free liquid which eventually drains from wastes in the landfill, plus the volume of precipitation which drains through the landfill. For a properly designed landfill, there will be no ground water entering the landfill. Similarly, surface drainage from adjacent areas will be diverted from the landfill.

Two cases need to be considered for the production of leachate:

- the case after closure of the landfill when an impervious cover has been installed and the principal source of leachate is that precipitation which infiltrates and percolates through the cover and the landfill;

- the case during operations when the liquid content of wastes and precipitation may contribute to leachate.

A water balance method can be used to estimate the volume of leachate generated. Computer models have been developed for this purpose as described in the foregoing EPA Reference 2. The basic equation for calculating the amount of percolation anticipated in a given time period and at a given site after closure is as follows:

$$PERC = P - R - ST - AET$$

Where PERC = Percolation, i.e. the liquid that permeates the cover and the waste and becomes leachate

P = Precipitation

R = Surface runoff

ST = Soil moisture storage, i.e. moisture retained in the soil after a given amount of accumulated potential water loss or gain has occurred

AET = Actual evapotranspiration, i.e. actual amount of water loss.

Given that precipitation and evapotranspiration are essentially regionally controlled, soil moisture storage and surface runoff are the two factors that the designer can adjust. Such adjustments are reflected in the design of the landfill cover. Soil moisture storage is a function of cover thickness. Runoff will be influenced by slopes, soil permeability, and vegetative cover. Local climatic conditions, i.e. precipitation and evapotranspiration will govern the extent to which it is feasible to reduce leachate production. The design of the landfill cover is discussed further in Section 10.5.

In the case of an operational secure landfill, the water balance method is still applicable in the form:

$$PERC = W + P - R - S - E$$

Where:

W = free liquid from landfilled wastes
P = precipitation (mean monthly values)
S = liquid in storage in the landfill
E = evaporation from the landfill
R = uncontaminated runoff from the landfill

As previously noted, this approach assumes that no surface drainage from adjacent areas or ground water enters the secure landfill. Similarly, all contaminated surface drainage within the landfill is assumed to stay within the landfill. This simple approach permits an estimate of the monthly or annual volumes to be handled by the leachate collection system. It also illustrates the rationale for limiting the direct landfilling of liquid wastes and the benefit of locations having a dry climate.

### b) Control of Leachate Head

The rate at which leachate can be collected and withdrawn from the landfill is directly related to the permeability of the material through which the leachate must flow to the collection system and the hydraulic capacity of the system. The potential for migration through the liner is minimized with the head on the liner. To maintain a minimum head of leachate above the liner, the use of a permeable drainage medium on the base of the site will generally improve the flow of leachate to the collection system and enhance the capability to remove the liquids from the landfill. The use of properly graded drainage media is recommended unless the permeability of the wastes deposited provides adequate drainage and presents no risk of clogging the system.

In addition, the spacing of the leachate collection pipes will influence the maximum head of leachate on the base of the fill. As a minimum, the leachate collection system should extend completely around the perimeter of the landfill to provide absolute control of the level to which leachate can rise on this critical boundary. An interior grid system of collection pipes may be required if the area of the site is large and/or the allowable head buildup cannot be maintained by a perimeter system. More details of the equations governing design of the collection system are found in the foregoing Reference 3.

Because migration of leachate via the liner is a long-term, rather than a short-term concern, short-term increases in the head on the liner can be tolerated. It is suggested, however, that an estimation of the head corresponding to extreme precipitation events and possible hydraulic, structural and operational consequences be considered during design. Such events, however, are of major significance to surface drainage design.

In summary, the hydraulic design of the collection system should consider: the leachate volume to be removed and the duration for its removal; the hydraulic capacity and the permissible leachate head. Design of the pipe and drainage materials and pumping equipment, if required, must also consider the leachate characteristics and long-term integrity of all materials, together with the structural stability of the pipe with reference to the weight of operating equipment and waste, and operation and maintenance needs. It is suggested that quantitative design guidelines be avoided, and that each site be considered on its own merits using these factors.

## 10.4 Leachate Treatment

Leachate collected and withdrawn from secure landfills must be treated or disposed of. The optimum method will depend on the characteristics of the leachate. As these characteristics will be highly waste dependent, the treatment options will be correspondingly diverse. A detailed treatment of these options is provided in the foregoing Reference 5. A generalized discussion is presented below.

The available options can be broadly divided into off-site and on-site treatment. It is generally agreed that on-site treatment is preferable, particularly if the characteristics of the leachate are such that it must be handled as a hazardous waste. It is possible that the leachate may be recycled through on-site pre-treatment processes used for incoming wastes; or handled by existing treatment units if the landfill forms part of a treatment and disposal complex. Alternatively, leachate may be handled by a purpose-built treatment system. There is limited experience with such systems. As a result, performance and design criteria are not well developed. It is recommended, therefore, that consideration should be given in the planning stage to leachate characteristics, quantity and variability over time in relation to the types of unit processes available. Leachate treatability studies should be carried out to develop design criteria and to identify the most suitable physical-chemical treatment process (or processes, since more than one process may be required). At the same time, consideration should be given to the discharge criteria of the local jurisdiction for discharge of treated effluent.

For off-site treatment, the broad options are the use of other hazardous or industrial waste management facilities, or the use of a municipal sewage treatment plant. The latter is unlikely unless leachate is shown to be non-hazardous and compatible with the municipal treatment process, subsequent to dilution.

It should be borne in mind that an off-site facility, not operated by those responsible for the disposal site, may create liability problems. Different operators may not accept the liabilities associated with treating the leachate because of the variations over time in the quantity and quality of leachate.

## 10.5 Final Cover

The current philosophy in secure landfill design is that after closure, the final cover (or cap) becomes the prime element in the overall liquids management strategy. As previously noted, a well designed and carefully maintained cap can be effective in reducing the volume of liquids entering a landfill, and can thus reduce the potential for leachate generation for long periods. In addition to acting as a barrier to minimize infiltration, the cap must be designed with consideration of other factors including:

- gas migration
- freeze/thaw or dry/soak effects
- trafficability and support requirements
- cracking and differential settlement
- vegetative requirements
- erosion control

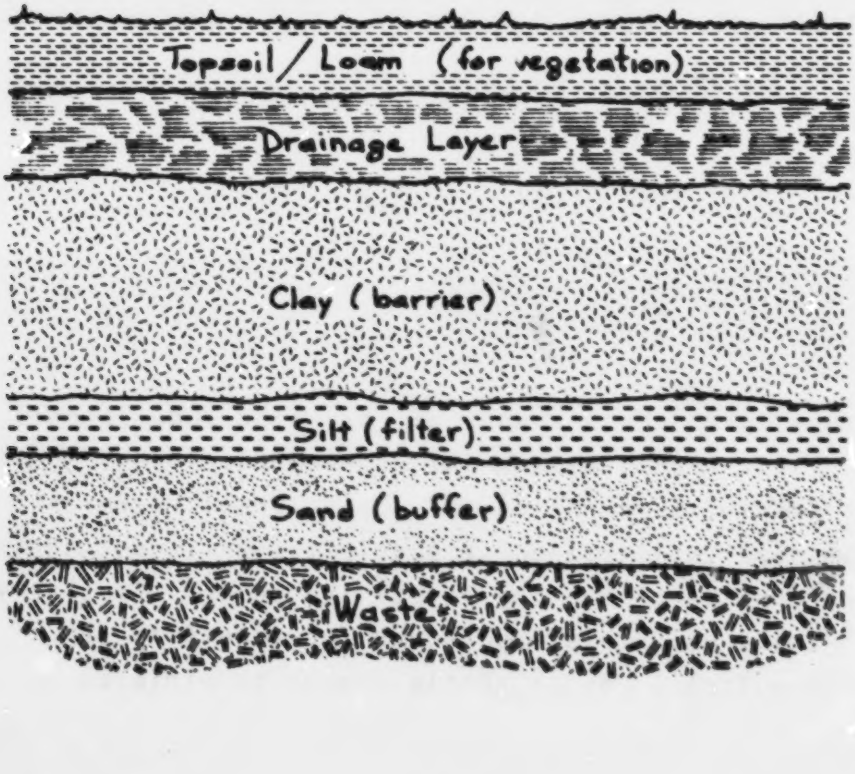
These factors introduce a number of competing requirements for the configuration and material of construction of the cap. For example, a compacted soil or polymeric membrane used to minimize infiltration of precipitation is not consistent with promotion of healthy vegetative cover. Similarly, final contours should be steep enough for runoff to be carried away quickly, yet be gentle enough to minimize erosion.

Clearly, an ideal cover design of a single material cannot be conceived in a manner which reconciles all these conflicting objectives.

A proposed solution to this problem is that of layering. This concept combines several types of materials which collectively attempt to resolve the conflicting objectives. The concept of layered covered systems is discussed in more detail in the foregoing Reference 1. An example of the layering concept is shown in Figure 8.

FIGURE 8

**Layering Concept for Landfill Covers**


Topsoil/Loam (for vegetation)
Drainage Layer
Clay (barrier)
Silt (filter)
Sand (buffer)
Waste

The primary feature in the layered system is the barrier, which functions to restrict passage of water or gas. The barrier may be constructed of clay, or polymeric membranes may be used. Each has its own advantages and disadvantages: soil barriers are susceptible to deterioration by cracking when exposed at the surface, whereas membranes are more prone to damage. In Figure 8, the loam placed above the clay barrier is designed to act as a buffer to protect the clay from drying out and, at the same time, to provide a suitable growth medium for vegetation.

In some cases, a drainage layer may be incorporated above or below the barrier to facilitate runoff and minimize infiltration into the waste. Where grossly discordant grain sizes are joined, there may be a tendency for fine particles to penetrate the coarse layer. As a result, the effectiveness of coarse layers used for drainage may be reduced by clogging of the pores. A layer of intermediate grain size may be helpful in alleviating this problem, e.g. the use of a silt filter between the sand and clay layers shown in Figure 8. Alternatively, a filter fabric or cloth may be considered instead of a soil filter layer.

There are many possible variations in the design of a layered covered system and it is considered inappropriate here to recommend specific design standards.

Each design will need to be tailored to the requirements of the specific site. Two important guiding principles, however, are proposed. The cover design should be such that its permeability is less than or equal to that of the landfill liner, in order to prevent the build up of liquid head within the landfill after the leachate collection system has ceased operating. This is the so-called "bath-tub effect". To minimize conflicting objectives, a clearly-defined set of site-specific criteria should be established at the outset of design considering infiltration, gas migration, vegetation, after-use of facility and the physical effects of weather.

## 10.6 Drainage Control

### a) Surface Water Run-on Control

Control of surface water run-on is intended primarily to restrict the amount of drainage into the active areas of the landfill and to minimize leachate production as much as possible. In addition, control of run-on helps to limit side slope erosion and operational problems associated with traffic and on-site vehicles.

All surface water run-on should be diverted away from active areas of the facility. Diversion may be accomplished by use of natural topography as well as man-made berms and diversion channels. The design should be compatible with the operation of the facility. Capacity of such works should be based on a thorough hydrological and hydraulic analysis and allow for the intended phasing of the landfill and the size of the active area.

The hydrologic design of such analyses should consider short duration-high intensity precipitation events producing high rates of flow. A range of frequencies for these events should be considered in the analyses to permit assessment of the effects of extreme events (such as the 100-year storm) in addition to more frequent events normally used for the design of surface drainage works.

### b) Surface Water Runoff Control

Surface water runoff essentially involves the active portions of the landfill during operations, closure, and post-closure. The closure and post-closure implications are dealt with in Section 11. Control of surface water runoff, therefore, refers to runoff from the active areas of the landfill.

A hydrologic and hydraulic analysis, as described for run-on control, is required with consideration of extreme events.

Generally, runoff is controlled by minimizing run-on, collecting and managing runoff from the active areas and preventing the direct disposal of liquids. The runoff may be either contaminated or not depending on whether it has been in contact with wastes. If chemical analysis indicates that the runoff is contaminated, it must be treated as a hazardous waste and managed as such.

Various options are available to collect the runoff including permanent and temporary works such as berms, dykes and culverts. Once collected, and depending on the quality and the composition, the treatment options are numerous. If contaminated, these options are the same as for the leachate treatment options given in Section 9.

## 10.7 Landfill Cells

The normal operation of a secure landfill involves progressive filling using the cell concept which physically separates different areas of the site. The cell concept allows a more controlled landfilling operation by restricting filling to specific areas. At the same time, the construction of separate cells with individual liners, leachate collection systems, and drainage controls, permits more effective control of leachate and drainage from defined areas of the landfill.

In addition, the limited number of land disposal sites available dictates that one landfill facility be capable of accepting a broad range of hazardous wastes. The concept of cells, then, is a valid mechanism specifically for physically separating wastes by type and allowing good documentation of the location of the disposed wastes. Segregation of the wastes can be by chemical properties, physical properties or operation. Each is a discrete landfilling area separated by impermeable barriers.

The consideration of waste incompatibility is often referred to in the literature as a reason for separate cells or subcells. In practice, the restriction of the waste types itemized in Section 9, e.g. liquids, and reactive wastes may essentially eliminate such a rationale. Despite this, the concept of cells still remains valid.

## 10.8 Structural Stability

Structural stability can refer to either the stability of the wastes to be deposited, or the stability of earthworks (slopes and berms) or other structures.

Deposited wastes should be characterized by a structural stability that would allow normal landfilling operations to take place. Load bearing capacity should be such that landfill compactors can be used without the material collapsing.

Stability of side slopes and berms should be such that they can sustain loads in the same way as deposited wastes. In general, side slopes and berms should not exceed 2:1.

Short and long-term settlements must be considered in relation to the landfill, the leachate collection systems and all other components.

## 10.9 Site Layout

The site layout of the facility, which includes the landfill as well as treatment plants, incineration or other components of the system, will be dependent on the physical characteristics of the land. In this section, other key features required to make the facility function are addressed.

### a) Fencing

For site security reasons, fencing is a general requirement of hazardous waste facilities. It should be designed to prevent unauthorized persons and animals from entering.

A woven steel mesh fence, a minimum of 2 m high, placed around the site is suggested as a minimum standard.

### b) Access Roads

Access roads should be designed for all-weather purposes as well as to serve the basic needs of the site operation. They should allow easy passage of on-site vehicles without causing delays or hazardous conditions.

An all-weather access road should be a mandatory requirement within the secure landfill site.

### c) Visual Screening

Visual screening, through the appropriate use of vegetation and berms, should be used to limit views from adjacent lands. The existence of suitable screening may also be incorporated as part of the site selection criteria.

### d) Buffer Zone

It is a general requirement of all waste disposal facilities that a buffer zone be established between the active parts of a facility and its property line. Most jurisdictions have established or proposed a buffer distance requirement ranging from 10 m up to 100 m or more.

The intent of a buffer zone can be stated as follows:

i) To be able to contain on the facility property, all wastes, spills and hazardous conditions which may arise in the operation of a facility.

ii) To provide adequate contingency working area in a case where ground water contamination is detected in order that mitigative measures may be taken before contaminants cross the property boundary.

iii) To provide a physical barrier to limit visual access to the site by establishing berms or vegetation in the buffer zone, and to minimize disturbance to surrounding land uses.

### 10.10 Support Services

#### a) Laboratory

A laboratory should be located on site with the secure landfill. It should be adequately staffed and equipped to carry out routine testing of incoming wastes and for the operational control of any on-site pre-treatment facilities.

#### b) Maintenance Facilities

Maintenance facilities should be located on site with trained staff capable of carrying out routine maintenance on mechanical equipment.

#### c) Occupational Safety and Health

The secure landfill facility should include adequate facilities for worker safety and health, e.g. shower, changing rooms, etc. in accordance with the local occupational safety and health regulations.

#### d) Staffing

The personnel operating the various components of the facility must be trained to carry out their duties in a way that ensures the protection of human health and the environment.

The staff operating the facility should not only be trained to carry out the assigned duties, they should also be trained to:

- respond to emergencies, i.e. familiar with emergency equipment and procedures;
- institute contingency measures;
- respond to spills, fires or explosions;
- carry out shut-down of operations.

Adequate safety and first-aid equipment should be kept on site with operators trained in its use, e.g. self-contained breathing apparatus, fire extinguishers, etc.

## 11. OPERATIONS, CLOSURE AND POST-CLOSURE

### 11.1 Site Operations and Controls

The procedures for handling wastes at a secure landfill and related site operations should follow essentially standard operating practices, whether the landfill forms part of a waste management complex or is the only facility at the site. On receipt at the facility, the waste shipment should be checked for the appropriate documentation, packaging and labelling requirements. It should be sampled and analyzed to ensure consistency with the documented description. It should then be directed to the appropriate part of the facility, which may be either directly to the landfill or to a pretreatment unit. After pretreatment (if necessary), the waste is deposited, under the direction of site personnel, compacted in place by site plant, and its location recorded.

To ensure that these operations are carried out appropriately and consistently, control mechanisms are required and should be documented in a series of operational manuals, with provision for revisions and updating. These manuals should address as a minimum:

- operation and maintenance procedures;
- facility description and design parameters (see Section 10);
- emergency shut-down procedures for fixed plant (if any);
- safety procedures and requirements;
- staff responsibilities and reporting structure.

The recommended controls relating to the receiving and handling of waste shipments are elaborated below:

### a) Analysis and Testing

Analysis and testing is required to determine the chemical and physical characteristics of a waste. The analysis and testing provides the basis for determining whether the wastes can be directly landfilled, pretreated and landfilled, or must undergo alternative treatment, storage or disposal. Analysis and testing is therefore a critical factor in the safe management of the facility.

Before the facility contracts with a waste generator to accept a hazardous waste shipment, detailed chemical and physical analysis on a representative sample should be undertaken. This sampling is the basis for establishing if and/or how the waste should be handled at the facility, including pretreatment requirements and the important consideration of waste compatibility (see Appendix I).

On arrival of the waste at the facility, a series of spot checks should be carried out to ensure that the characteristics of the waste are consistent with the initial analysis. For operational feasibility, those checks should be restricted to tests that can be carried out in a relatively short period of time, e.g. simple tests such as pH, oil content, colour, odour, flashpoint, and/or automated techniques involving minimal sample preparation. Should a waste shipment not conform to the documented description, the facility's owner/operator may reasonably require more detailed testing either at the facility or elsewhere before accepting the shipment; or may choose to reject the shipment.

The detailed analysis and testing should be repeated whenever there is a change in the industrial or other process generating the hazardous wastes.

### b) Labelling and Packaging

All wastes received at a secure landfill facility should be packaged and labelled in accordance with the requirements of the Transportation of Dangerous Goods Act. The Act requires all dangerous goods, including hazardous wastes, to be properly identified by waste type and hazard class, and shipped in containers, e.g. drums, tank trucks, etc. that conform with prescribed performance standards and specifications.

### c) Documentation

Waste shipments should be accompanied by documentation that serves three functions:

- a control document for transportation;
- a control document for regulatory authorities to ensure that the waste is disposed of appropriately; and
- a control document for the site operator to ensure that the waste is handled appropriately at the secure landfill.

The first of these requirements is mandatory under the Transportation of Dangerous Goods Act; the second, which is generally referred to as a Hazardous Waste Manifest, has been implemented at the provincial level by Ontario and is under consideration in other provinces. At the same time, a Uniform Hazardous Waste Manifest has been proposed for international/interprovincial shipments, which would act as both a shipping declaration and which would direct shipment to a particular disposal point. A copy of the proposed manifest and the description of its control mechanism is provided in Appendix M.

The third requirement is generally a documentation system specific to individual site owners/operators. Such a system might include the following steps:

- detailed waste characterization as described in item (a);

- development of an appropriate handling, disposal document, including safety precautions, waste characteristics, pretreatment requirements;

- dispatch of handling and disposal document to waste generator;

- waste shipment to be accompanied by handling and disposal document.

It is possible that such information could also be handled on a single control document, which would minimize paper work, and some provision has been made for incorporation of handling instructions on the Uniform Hazardous Waste Manifest.

### d) Inspection and Maintenance

The operator of the facility must, as a standard procedure, inspect all components of the facility for malfunction, deterioration, poor operation and unplanned discharges which may lead to hazardous conditions, contaminations of the environment, or a threat to human health.

Operators should establish a scheduled inspection and maintenance program for all site components of the facility. Inspection should include all mechanical equipment, including monitoring works structures such as berms and covers, emergency equipment, security and monitoring equipment. Finished areas of the landfill should be checked for cover integrity. Inspection and maintenance activities should be routinely logged.

Detailed records of the inspection and maintenance should be kept on a form with a checklist of items to be inspected or maintained along with the identity of the inspector, date and any comments on corrective actions. These inspection and maintenance forms should be kept indefinitely. Frequency of the inspection and maintenance should be established prior to facility approval, and should take into account the time required for response and remedial actions.

### e) Record-Keeping

Maintaining records of wastes received and the location of the wastes within the landfill should be an integral part of site operations. The waste locations relative to control monuments and benchmarks should be identified. Records should indicate type of waste and quantity on a map, and should be cross-referenced to the documentation for each waste shipment. Accurate record-keeping will ensure sufficient knowledge of the types and locations of wastes to enable proper operation and closure, as well as remedial actions, if required. For example, if ground water has been shown to be contaminated, the wastes could be identified and removed or other appropriate remedial actions taken.

Similarly, records should be maintained for all site maintenance and operations including:

- site inspections
- equipment maintenance
- incident reports
- monitoring results.

### f) Security

The nature of secure landfill operations is such that security is a major concern. No animals or unauthorized persons should be allowed access to the site.

The entire facility should be fenced with access controlled by lockable gates and manned by security personnel during the hours that wastes are received. A 24 hour surveillance system to continuously monitor and control entry should be considered on a site specific basis.

Signs should be posted clearly visible from a distance of at least 10 m. Signs should be located along the fence in sufficient numbers to be clearly visible from any approach direction. Security requirements for post-closure should be established during the closure period.

## 11.2 Monitoring

It is generally accepted that monitoring is an essential part of the operation and maintenance of a secure landfill facility. Monitoring should be carried out prior to detailed design of the landfill to establish baseline conditions for the site. Monitoring should also be continued to post-closure. It is the means by which the performance of the facility is measured and problems are identified before they become serious.

To be effective, monitoring must be associated with contingency plans, so that corrective actions can be taken when warning signs are detected. For example, detection of ground water contamination would trigger more intensive monitoring to determine the source and nature of the problem, and subsequent remedial action to mitigate ground water contamination.

### a) Ground Water Monitoring

The ground water monitoring program at a secure landfill is the most important means by which the satisfactory performance of the landfill's containment function can be assessed. Ground water monitoring requirements are usually specified by regulatory authorities on a site-specific basis, dependent on hydrogeologic conditions, wastes deposited, site design etc. Some alternative approaches, however, can be considered and guidelines proposed.

The objective of the ground water monitoring program is to ensure that ground water quality is not adversely affected by the landfill to an unacceptable degree. Ground water observation wells are used for this purpose, and should be installed upgradient from the site as well as downgradient. The upgradient wells are used to establish background water quality in the area of the landfill prior to and during operation of the landfill. The impacts of the landfill may then be measured by comparing monitoring results downgradient with the upgradient or background results. Number of wells, depth and monitoring frequency should be determined by site-specific conditions. Parameters to be monitored initially should be indicator parameters such as specific conductance, TOC, TOH, pH, and/or other parameters based upon the hazardous constituents of the waste deposited.

As a basis for discussion, the list of hazardous constituents adopted by the U.S. Environmental Protection Agency is proposed as a reference point, and is included in Appendix F.

In the event of significant impacts being detected, it is recommended that a more detailed monitoring program be initiated, likely involving additional parameters and increased frequency. The precise nature of the more intensive program would be determined by site-specific conditions. Three other important considerations should be considered:

- the point at which the impact of the site on ground water should be measured;
- the concentration limits above which corrective action must be taken; and

- the variance of monitoring results from the established concentration limits that is considered statistically significant.

i) Monitoring Boundary

In selecting a location for assessing the impact of the site on ground water there are essentially four options: at some point directly below the waste; at the property boundary; at the edge of a buffer zone within the property; or at the edge of the waste management area, i.e. immediately outside the berms and dykes associated with the landfill.

Of these options, the first involves either drilling through the waste or using angled monitoring wells, neither of which would be desirable. Monitoring at the property boundary is more practically feasible, but could result in a significant amount of ground water contamination occurring before the problem is detected. It is therefore not considered desirable.

Monitoring at the edge of the buffer zone or the edge of the waste management area are both considered possible options. The difficulty with a buffer zone arises in defining a suitable distance. Since this distance should logically be related to ground water flow rates, it would be highly site-specific. It can also be argued that the use of a buffer zone could still allow a significant amount of ground water contamination to occur before the problem was detected. These disadvantages are overcome by using the edge of the waste management area as the compliance point. This requirement may be overly stringent in hydrogeologic settings where soil attenuation mechanisms will effect rapid contaminant removal, and/or ground water has no resource value.

On balance, it is considered that monitoring at the edge of the waste management area is the most effective way of maintaining ground water control, and that any variances in meeting ground water protection standards (because of site-specific considerations) should be on the basis of relaxations in concentration limit, rather than on monitoring location.

ii) Concentration Limits

Three options are considered here for establishing concentration limits for ground water monitoring: detectability of the constituent in ground water; numerical limits for each constituent based on health and environmental effects and/or site-specific considerations; and concentrations in excess of background levels. The first of these is thought to be unsuitable in that constituents may be detected in the vicinity of the landfill as a result of other sources or may be naturally occurring in the local ground water. It would be unreasonable to penalize a landfill operator for pollution originating from another source.

The preferred approach is a combination of the other two options and would require that hazardous constituents in the ground water not exceed:

- the background level in the ground water for that constituent; or

- the maximum acceptable concentrations specified for constituents listed in Canadian Drinking Water Quality, 1978.

The reference to background levels is considered reasonable in light of the current state-of-the-art of analytical techniques, and avoids the difficulties in determining acceptable levels for substances, where health effect data is not clearly defined. Similarly, the use of drinking water levels limits the use of numerical standards to constituents for which health effects are well documented.

iii) Statistically Significant Variance

In carrying out the ground water monitoring program, a method is required to determine whether background values of monitoring parameters are exceeded at the compliance point. To do so, it is necessary to define what constitutes a "statistically significant" increase over background values at the compliance point. This determination involves the selection of a level of significance, the choice of a statistical test, and the requirements of the number of samples and the number of replicate measurements run on each sample. Since these considerations are all interrelated, what is required is a standard statistical procedure addressing all these areas.

A detailed discussion of available statistical procedures is beyond the scope of this document. Instead, an example is provided for discussion purposes by reference to that proposed by the U.S. Environmental Protection Agency. The essential features of this approach are as follows:

- Background levels should be determined by a minimum of one sample from each well and a minimum of four samples from the entire system each time the system is sampled. A minimum of four quarterly sampling efforts are required.

- Assuming the background level has a coefficient of variance less than 1.00, a sample should be taken from each well at the compliance point, divided into four portions, and analyzed.

- If the difference between the mean of the constituent at each well (using all four portions taken), and the background level for the constituent is significant at the 0.05 level using the Cochran's Approximation to the Behren's-Fisher Student's t-test (as described in Appendix G), the procedure should be repeated.

- If the second round of sampling and analysis indicates that the difference is significant, it must be concluded that statistically significant change has occurred.

### b) Surface Water Monitoring

Monitoring of surface water is an important component of the landfill operation and maintenance and is directly related to the control of surface run-on and runoff. Assuming drainage control for surface water is part of the site operations, monitoring is required to determine whether the water is contaminated and to determine the appropriate treatment and disposal methods. If hazardous contaminants are present, it must be treated as a hazardous waste. If no contamination is present, discharge to the nearest watercourse may be all that is required.

Permanent surface water monitoring stations should also be established upstream and downstream of all watercourses and drainage facilities in the drainage area of the facility. Monitoring should establish background levels prior to the start-up of the facility. Parameters for testing and frequency of sampling should be established on a site-specific basis using procedures parallel to those described for ground water monitoring.

### c) Leachate Monitoring

There are two components considered here: the monitoring of leachate characteristics as an indicator of the waste's leachability; and the monitoring of leachate quantity head within the landfill. Both are considered important additions to complement ground and surface water monitoring programs.

Leachate characteristics are a necessary input to assessing treatment requirements of the leachate, and should be monitored periodically depending on the sensitivity of the treatment process being used. Such data also forms a valuable input to establish appropriate monitoring parameters for ground and surface water monitoring programs.

At the same time, the measurement of leachate head within the site is an integral part of the leachate removal system, and in the long-term, provides data on the effectiveness of the final cover.

### d) Air Quality Monitoring

Given the limited information on air emissions from hazardous waste landfills, and the fact that the problem of air emissions appears to be highly waste-specific, it is difficult to provide extensive guidelines in this area. Each site must be considered on its own merits with account taken of the potential for volatile emissions from the wastes received and the types of operations performed on site, e.g. pre-treatment activities in open vessels, etc.

Where air monitoring is considered a necessary component of the overall monitoring program, air-monitoring stations should be installed in adequate numbers and locations to determine ambient air quality and to enable detection and quantification of hazardous constituents or decomposition by-products in the air.

### e) Biological Monitoring

Biological monitoring is the use of biota to evaluate the toxicity of effluents, leachate and other contaminated products from hazardous waste storage or disposal sites. Although the testing of biota usually occurs in laboratory situations using selected species, it is conceivable that in-situ monitoring of indigenous biota may be appropriate to supplement other environmental monitoring activities. The need for such monitoring would be highly site-specific, and some examples of biological monitoring techniques are presented here simply to illustrate the scope of such techniques.

- the use of modified Beak or Trent or similar biotic indices to evaluate pollutants in fresh-water streams potentially influenced by hazardous waste;

- sampling of vegetation on-site or within air dispersion isopleth limits for phytotoxic injury symptoms;

- monitoring of sensitive ecosystems or animal populations for chronic effects.

Biological monitoring usually involves bioassay. There are several bioassays that have been used in connection with hazardous wastes and waste effluent, including:

- *Daphnia magna* reproduction assay;
- $LD_{50}$, $LC_{50}$ tests using selected fish species;
- algal culture indicators;
- *Salmonella*/microsome mutagenicity test;
- tests on mutations in fungi;
- seed germination bioassays;
- seedling growth studies;
- DNA repair and recombination tests in selected bacteria.

These tests are designed to indicate low concentrations of hazardous and toxic substances and are specific for a given range of chemicals.

A major advantage in biological assays is that they are ideal in assessing potential chronic toxicity including bioaccumulation in food chains and sublethal impacts on reproduction, behaviour and general fitness. Results of bioassays should be confirmed with chemical tests and observations *in-situ* in indigenous populations.

### 11.3 Contingency Planning

Contingency plans are a normal requirement at all hazardous waste facilities to deal both with short-term incidents such as accidental spills, fires and explosions; and with long-term events, primarily those relating to ground water pollution. Because of the significant differences in the nature of the response to short and long-term events, they are treated separately here.

## a) Short Term Events

### i) Organization and Communications

The responsibility for responding to emergencies and initiating contingency plans should rest with the facility manager. The manager would rely on staff and equipment to contain the emergency with the least impact on the environment and human health. Most on-site incidents would be dealt with by the facility staff. However, depending on the severity and nature of the emergency, the police, fire department, local health boards and the provincial authority would be consulted.

### ii) Analysis and Response

Incidents can be broadly divided into those posing a high degree of hazard where immediate response is vital, and those of a less hazardous nature. The degree and nature of the hazard would determine the appropriate response action. Key elements of the response strategy are outlined below:

- Contingency plans are required to deal with spills, fires, explosions or generation of toxic fumes.

- Descriptions of planned responses to emergencies should be prepared prior to facility approval.

- Arrangements for local help should be made in cases of severe hazards or fires.

- An evacuation plan should be prepared.

- Emergency equipment should be routinely checked and kept in operational order.

- A residue management plan from the emergency should be prepared.

- The immediate assessment of hazard should be the first priority in determining an appropriate response.

b) Long-Term Events

The principal long-term concern associated with contingency planning at secure landfills is ground water pollution and, to a lesser extent, surface water pollution.

In the event that the monitoring program described in Section 11.2 indicates that the landfill has not met the required ground water protection standards, then corrective action must be taken until these standards can be achieved. Similar considerations apply to surface waters.

The techniques for undertaking such remedial actions are currently under intense investigation, as a result of the problems encountered with uncontrolled hazardous waste sites in North America and Europe, and particularly in the United States. These techniques for uncontrolled hazardous waste sites can, in many cases, be equally applied to corrective actions for secure landfills, should this be necessary. Unit operations proposed for ground water either individually or in conjunction follow:

- Well point system
- Deep well system
- Drain system
- Injection system
- Bentonite slurry trench
- Grout curtain
- Sheet piling cutoff
- Grout bottom sealing

For surface water control, the unit operations applicable are essentially maintenance of the design features, which should already be incorporated in the landfill, e.g. cover, integrity, drainage control. Further details of alternative remedial actions, are provided in the following publications:

- Guidance Manual for Minimizing Pollution from Waste Disposal Sites.

- Remedial Actions for Waste Disposal Sites: A Decision Maker's Guide and Technical Handbook.

- Costs of Remedial Response Actions at Hazardous Waste Sites.

## 11.4 Closure and Post-Closure

At the end of a landfill's active life, there are specific requirements that should be observed in the process of site closure and the post-closure period that follows.

Essentially, closure should be undertaken in a manner that minimizes the need for post-closure care and minimizes migration of contaminants from the landfill.

Closure and post-closure requirements are essential for the protection of human health and the environment in the long-term. Without a detailed plan covering maintenance, remedial works and contingency plans, and addressing such issues as future site land use controls, there is a possibility of contamination of surface and ground water, air and direct exposure to hazardous compounds. Contingency plans and remedial works are addressed in Section 11.4. Attention here is focussed on the closure process and ensuing maintenance activities.

The closure process should include the:

- placement of final cover and vegetation; and
- decontamination and/or removal of site works and buildings and equipment no longer required.

Post-closure requirements should include:

- maintenance of final cover and vegetation;
- continued monitoring of ground and surface water;
- continued maintenance and operation of the leachate collection and removal system;
- maintenance of site security;
- maintenance of control monuments and benchmarks used in identifying location of individual landfill cells.

The period of time for post-closure care has been a subject of much controversy. The U.S. Environmental Protection Agency has specified a period of 30 years after closure during which time monitoring will take place. It can be argued that some wastes will remain hazardous in perpetuity, which, in turn, implies a need for perpetual monitoring. The financial and social practicality of perpetual monitoring however is questionable so that in practice, some specified time period is required for post-closure care. While the 30 year period provisionally adopted by the U.S. Environmental Protection Agency has no rigorous rationale for its development, it is presented as an option for discussion purposes, with the proviso that it should be subject to site-specific considerations such as degree of hazard of the wastes, etc.

The major considerations in preparing and implementing a site closure and post-closure plan are amplified below:

a) Cover

The maintenance of final cover over the land disposal site is a pre-requisite to limiting infiltration into the fill area and consequently, production of leachate. As discussed in Section 10, the permeability of the final cover should be less than or equal to that of the liner or base of the site, in order to prevent the so-called "bath-tub effect".

The maintenance of cover should be based on regular site inspection and include:

- repairs to damage caused by erosion, settling, subsidence, or other events;
- vegetative repair;
- ensuring adequate drainage.

There are no easy procedures to limit the requirement for long-term maintenance at land disposal sites. Less frequent maintenance is possible if the final cover is over-designed.

In this case, some deterioration of cover or erosion may not affect the purpose of the cover, that is, to limit infiltration.

### b) Decontamination of Equipment/Site Works and Buildings

During closure all equipment, site works and buildings not required for maintenance during the post-closure period, should be decontaminated before removal from the site or otherwise safely disposed of.

### c) Monitoring

Long-term monitoring should be continued at all secure landfills during the post-closure period. Continued monitoring of ground and surface waters, in conjunction with a contingency plan, ensures that contamination potential is minimized. The same procedures should be employed as described for the operating period in Section 9.11.

### d) Control of Future Use

Ideally, the site of the secure landfill facility should include sufficient buffer such that restrictions on future development adjoining the site and along major access roads are not required.

If limitations are required, it is preferable that the site be located in an area where existing planning policies and restrictions provide essentially the same restrictions as those required once the facility is established.

The types of uses which should be discouraged are essentially the same as those which would be avoided in the site selection process. Examples include:

- residential development;
- uses which would result in a substantial increase in resident or temporary population levels surrounding the site, along major access road or downstream from major surface water streams in the immediate environs of the site;
- uses where populations would be especially susceptible to health-related effects or would be difficult to evacuate;
- uses where water requirements e.g. location of wells, withdrawal rates would increase potential risks associated with ground water contamination;
- uses which would result in a significant cumulative risk (the new use in combination with the hazardous waste landfill);
- uses which would result in an increase in community disruption effects, e.g. noise, visual intrusion.

Policies regarding control of future land use should be the product of discussions with municipal representatives and affected landowners. Since there is the potential for the loss of "development rights" through such limitations, consideration may need to be given to additional direct purchase or compensation.

Once the policies are established, they should be incorporated into local community plans. All affected owners should be notified.

## 12. IMPACTS AND MITIGATIVE MEASURES

### 12.1 Introduction

The analysis of community and environmental impacts for the selected site represents a refinement of the concerns addressed in the site suitability analysis (Section 8).

This refinement process occurs prior to design through detailed site investigations which serve to ensure that the design is compatible with site conditions. It also occurs in conjunction with design, construction and operations (Sections 10 and 11). The analysis of impacts provides the basis for the formulation of measures to reduce, overcome or compensate for adverse community and environmental impacts and for the determination of appropriate monitoring measures.

As in site selection, anticipating and offsetting potential sources of risk is especially important. There is also a particular need for an intensive effort at public consultation.

### 12.2 Detailed Site Investigations

The scope of detailed site investigation will vary considerably depending on the nature of the facility, the site and the areas surrounding the site and access roads. Table 12 provides a list of some of the site-specific studies which may be required.

These site-specific studies are intended to serve a number of important functions including:

- the establishment of baseline conditions;
- the identification of those aspects of the natural and socio-economic environment which are particularly significant or sensitive to adverse impacts;
- the identification of local issues and public concerns;
- the identification of opportunities for providing and enhancing benefits;
- the provision of site-specific information for the adaptation of environmental models;
- the provision of site-specific information to assist in the design and layout of the facility;
- the provision of site-specific information to assist in the formulation of construction and operational procedures;
- the determination of appropriate monitoring and contingency planning procedures;
- the determination of appropriate interim and after-uses for the site;
- the determination of appropriate controls for uses surrounding the site and along the major access roads.

The purpose for each component of site-specific environmental studies should be clearly defined. In this way, needless information gathering, at inappropriate levels of detail, will be avoided.

## TABLE 12

## EXAMPLES - DETAILED SITE INVESTIGATIONS

### GROUND AND SURFACE WATER

- Test drillings, geophysical testing and soil sampling.
- Analysis of overall geological character of rocks, depth of strata, ground water and chemical and physical character of soils, clays and rock, including cover material availability and suitability.
- Determination of existing subsurface water quality and flow including other sources of contamination and their cumulative impact on water quality.
- Current and projected withdrawal rates of ground water users.
- Surface drainage patterns including susceptibility to flooding.
- Existing surface water quality including other sources of contamination and their cumulative impact on water quality.
- Location, requirements and type of surface water users.
- Current and potential links between ground and surface water.

### CLIMATE AND AIR QUALITY

- Precipitation patterns.
- Meso- and microclimate variables, wind direction and speed including relationship to local topography, temperature, albedo, evapotranspiration, soil temperature regime.
- Existing air quality including other sources of contamination and their cumulative impact on the area.

### BIOLOGICAL

- Analysis of terrestrial and aquatic ecosystems.
- Detailed analysis of environmentally sensitive and significant areas.
- Biophysical capability analysis, e.g. agriculture, forestry, recreation.

## TABLE 12

## EXAMPLES - DETAILED SITE INVESTIGATIONS

(continued)

- Analysis of potential damage to wildlife, vegetation and crops.
- Analysis of suitability of local vegetation for cover materials.
- Analysis of potential entry of waste constituents into agricultural, natural terrestrial and aquatic food chains.
- Effects of airborne contaminants, phytotoxicity.

SOCIO-ECONOMIC

- Surveys of cultural, scientific, historical and archaeological resources.
- Analysis of existing, committed, planned and proposed land uses near site and along access roads.
- Analysis of roads and utilities potentially affected by facility.
- Existing and projected traffic conditions (with and without facility).
- Ambient and forecasted noise analysis (site operations and access roads).
- Consideration of potential traffic conflicts, e.g. school bus movements, agricultural vehicles.
- Detailed analysis of operations of businesses most directly affected.
- Analysis of visual characteristics of site and access roads.
- Municipal service and financial analysis.
- Research on community attitudes, concerns and activities.
- Socio-economic profiles, community infrastructure impacts.

Wherever possible, baseline data should be obtained over as long a period of time as possible. In this way, projections of conditions with and without the facility will be made with much greater accuracy and precision.

A particular effort should be made to identify interrelationships among environmental components and areas of uncertainty.

## 12.3 Potential Impacts and Mitigative Measures

If a thorough and systematic site selection process has been undertaken, the magnitude and significance of site-specific risks should be limited.

As no site is ideal, there will inevitably be some impacts. There will always be a need to build "safeguards" into the design and operational procedures of the facility. There will also be a need to establish a comprehensive monitoring system. The monitoring system will serve to:

- determine if baseline conditions change as predicted;
- determine if impacts occur as predicted;
- identify releases of contaminants such that appropriate mitigative actions can be taken before their escape from the site.

Table 13 identifies several potential impacts and provides a partial list of potential mitigative and monitoring measures. The mitigative measures pertain to both design and operations.

Particular emphasis is again given to identifying and responding to potential risks to human health and the environment and to matters bearing on the issue of community acceptance.

## TABLE 13

## POTENTIAL IMPACTS AND MITIGATIVE AND MONITORING MEASURES

| POTENTIAL IMPACTS | MITIGATIVE MEASURES AND MONITORING |
|---|---|
| **Surface and Ground Water** | |
| . contamination of ground water | . leachate monitoring, collection and withdrawal system<br>. sealing of fractures or features of questionable permeability<br>. installing clay and synthetic liners - extra thickness, multiple liners<br>. ground water monitoring systems on site and in potentially affected areas<br>. subsurface "slurry wall" barriers<br>. controls on other ground water withdrawals in area |
| . potential effect on aquifers | . provision of alternative water supply system<br>. special "environmental impairment" insurance<br>. well monitoring |
| . potential effect on surface water | . collection system for surface water runoff<br>. curbing and berming |
| . potential effect on public water supplies | . special runoff collection and treatment<br>. provision of alternative water supply system<br>. water quality monitoring |
| . potential for earthquake activity | . water quality monitoring<br>. special facility design<br>. evacuation plans |
| . infiltration | . revegetation<br>. impermeable cover<br>. erosion and sediment control<br>. contouring<br>. surface modification (e.g. compaction) |
| **Air** | |
| . potential human exposure to air pollution | . air monitoring and contingency planning |

## TABLE 13

## POTENTIAL IMPACTS AND MITIGATIVE AND MONITORING MEASURES

## (continued)

| POTENTIAL IMPACTS | MITIGATIVE MEASURES AND MONITORING |
|---|---|
| Natural Environment | |
| . contamination of surface water features | . berming and curbing<br>. surface water traps and sinks<br>. watershed isolation |
| . soil contamination | . soil removal contingency plans |
| . food chain contamination | . isolation, buffers |
| . destruction of natural habitat | . revegetation with native stock<br>. buffers |
| . noise and movement disturbance | . noise protection structures<br>. noise and visual buffers<br>. isolation and special distancing<br>. scheduling construction to non-sensitive periods<br>. monitoring to ensure natural features and resources maintained |
| Land Use | |
| . proximity of site or transportation route to residences and sensitive facilities | . relocation of uses<br>. purchase of buffer zones or development rights on adjacent lands<br>. reduction in facility size<br>. orientation and layout of site plans<br>. location, extent and phasing of landfill operations<br>. aesthetic design of facility and landscaping<br>. use of existing vegetation and topographic features for screening<br>. noise berms<br>. hours of operation<br>. interim and after-use planning |
| . compatibility with land use plans | . development control adjoining site and along major access roads<br>. interim and after-use planning |
| Transportation | |
| . safety of transportation route | . transportation re-routing<br>. selection of access routes and access points |

TABLE 13

POTENTIAL IMPACTS AND MITIGATIVE AND MONITORING MEASURES

(continued)

| POTENTIAL IMPACTS | MITIGATIVE MEASURES AND MONITORING |
|---|---|
| Transportation (cont'd) | |
| | . access road construction<br>. truck safety features<br>. controls of truck movements to minimize interference with school buses and agricultural vehicles |
| . potential for noise impacts | . limitation on hours for delivery<br>. muffler installation |
| Economic | |
| . potential effects on property values | . payments to neighbours for diminished property values<br>. land-value guarantees (conditional payments) |
| . impact on existing or future economic activity | . free disposal for local industries<br>. hiring and purchasing practices<br>. training programs<br>. local business opportunity plans |
| . effects on municipal services and finance | . direct grants in lieu of taxes<br>. provision and improvement of public services<br>. impact studies<br>. planning grants<br>. provision of emergency facilities<br>. monitoring of long-term economic and financial impacts and the use of procedures e.g. agreements to guarantee compensation and to provide additional benefits |
| Social | |
| . community objections and concerns | . ongoing procedures to involve agencies, businesses, interest groups in design process, operations, closure and post-closure planning and monitoring<br>. institution of grievance, negotiation and compensation procedures for nuisance and risk |

Consistent with the recognition of the inherent imbalance in the distribution of costs and benefits, emphasis is placed on negotiating areas of disagreement and on the provision of benefits and compensation.

Given the probability for misinformation, an open and ongoing community consultation program is suggested. This program should be maintained through the design, construction, operations, closure and post-closure periods.

It is important that the residual impacts, i.e. impacts after mitigative measures, are clearly identified. Any uncertainties concerning the effectiveness of mitigative measures should also be determined.

As the residual impacts and risks generally form the basis for final project approval or rejection, an interpretation of the significance of each residual impact and potential risk should be prepared together with a rationale for the decision reached.

## 12.4 Community Consultation

Consultation with municipalities, interest groups and potentially affected residents should not end with the closure of the facility.

Procedures should remain in place for:

- responding to any area of concern identified;
- providing all interested parties with the results of the monitoring program;

- providing all interested parties with information concerning the status of the after-use;
- providing information and resolving any concerns with respect to site maintenance and security;
- providing an independent forum for the resolution of any areas of dispute;
- ensuring that commitments made concerning protective measures, "guarantees", compensation, etc. are fulfilled;
- addressing issues related to development proposals and development control.

## 12.5 Financial and Liability Considerations

The whole area of financial and liability considerations is a difficult and important field requiring particular attention. Consideration must be given to financial capability in terms of day-to-day operations and closure, liability in the event of an accidental release, and post-closure maintenance monitoring and protection. If financial and liability concerns are not adequately addressed there is a danger that the owner/operator could face bankruptcy which could, in turn, result in a serious financial burden on a provincial government and could potentially represent a threat to human health and the environment.

A variety of approaches are possible in this area. As a general principle, the intent ultimately should be to recover the cost of operations and liability for the operations, closure and post-closure periods through disposal rates. The approaches may include combinations of such techniques as:

- bonding and bonding/fee combinations
- non-sudden, non-accidental insurance
- liability insurance
- a waste management fund for costs not covered by liability insurance and instances where immediate action is required but is not possible because of insurance requirements.

Numerous variations of these approaches are possible. Insurers may, for example, insure facilities on an individual basis or form pools to insure facilities for non-sudden and sudden occurrences. Fees may be charged on a volumetric or on an industry-wide basis. Funds can be administered privately or by provincial agencies. Various types of cash performance or surety bonds can also be employed.

The approach which is appropriate for a particular province and a particular facility will depend on a variety of factors such as:

- the types and quantities of waste
- relevant provincial legislation
- the characteristics of the site, the area surrounding the site and the potential risks and impacts
- the amount of liability insurance available
- the maximum amount payable by a policy
- the areas which cannot be covered by insurance

It will, at some point, be necessary to establish a time limit for long-term monitoring and care e.g. 30 years after closure at which point the financial responsibility of the owner/operator ceases and the province assumes future responsibility. It will also be necessary to formulate a program for making refunds and disbursements once funds and services are no longer required.

Careful consideration will need to be given to how the system is to be implemented and administered. In particular, if waste management funds are established, the criteria for the amount and methods of payment must be clearly established.

The whole field of financial and liability concerns is new and requires a cooperative effort on the part of owners/operators, government agencies and the insurance industry.

Environment Canada Environnement Canada
2035108C VOL ISS 7
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<REPORT> WM

OOFF

# LANDFILLING OF HAZARDOUS WASTES

## Appendices

WM-7

# LANDFILLING OF HAZARDOUS WASTES
## Appendices

by

M.M. DILLON LIMITED

for the

Waste Management Branch
Environmental Protection Service
Environment Canada

This report has not undergone detailed technical review by the Environmental Protection Service and the content does not necessarily reflect the views and policies of Environment Canada. Mention of trade names or commercial products does not constitute endorsement for use.

This unedited version is undergoing a limited distribution to transfer the information to people working in related studies. This distribution is not intended to signify publication and, if the report is referenced, the author should cite it as an unpublished report of the Branch indicated below.

Any comments concerning its content should be directed to:

Waste Management Branch
Environmental Protection Programs Directorate
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

April, 1983

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# APPENDIX A
# FORM LETTER REQUESTING INFORMATION

9133-01

26 January 1982

Attention:

Guidelines for Landfilling of Hazardous Wastes

Dear Sirs:

We have been retained by Environment Canada to prepare guidelines for the landfilling of hazardous wastes. As these guidelines are intended to have application throughout Canada we would like to solicit your input on the content and structure of the guidelines.

The scope of the study is quite broad and is intended to provide a code of good practice for all aspects of disposal by secure landfilling from siting through design to closure and post-closure care. The guidelines are not intended to have any regulatory status.

A copy of the Terms of Reference for the study is attached to provide you with more information. We would point out that, following the completion of the draft guidelines at the end of March 1982, Provincial agencies, industry associations and other interest groups will be invited to participate in a detailed review process. While this review process will provide an opportunity for you to comment upon their guidelines, you may also wish to provide some input to their content and structure at wish to provide some input to their content and structure ac this early stage of development. In addition, it would be helpful if you could supply us with copies of all Provincial guidelines or regulations which may be relevant to the study.

...continued

Because of the limited time frame we have to complete the study, we would be grateful if we could have your response no later than 26 February 1982. If you have any questions please call.

We look forward to hearing from you.

Yours truly,

M. M. DILLON LIMITED

M.P. Scott, M.Sc., M.C.I.C.
Project Manager

cc: A. Burgess - Environment Canada

# APPENDIX B
# AGENCY RESPONSES

# APPENDIX B

## Agency Responses

The following list identifies the agencies responding to the letter of request for information given in Appendix A. Letters of response from the agencies are attached for reference.

- Nova Scotia Department of the Environment
- Quebec Ministry of the Environment
- Manitoba Environmental Management Division
- Alberta Environmental Protection Services, Pollution Control Division, Waste Management Branch
- New York State Department of Environmental Conservation
- West German, Federal Environmental Agency
- New Jersey State Department of Environmental Protection, Solid Waste Administration
- Minnesota Pollution Control Agency

~~JAH~~

**NOVA SCOTIA**
**DEPARTMENT**
**OF THE**
**ENVIRONMENT**

*P.O. Box 2107 Halifax, Nova Scotia B3J 3B7*

RECEIVED
MAR 1 1982
M. M. DILLON LTD.
TORONTO OFFICE

*Your File:* 9133-01

*Our File:* 1500-2

February 25, 1982

FILE 9133-01
~~JAN~~
~~DPC~~
file

Mr. M. P. Scott, M. Sc., M.C.I.C.
Project Manager
M. M. Dillon Limited
Box 219, Station K
Toronto, Ontario
M4P 2G5

Re: Guidelines for Landfilling of Hazardous Wastes

Dear Mr. Scott:

Thank you for your letter of January 26 regarding guidelines for landfilling hazardous wastes.

For your information, I am enclosing two documents:

1) Draft Guidelines for the Selection of Chemical Waste Landfills

2) Guidelines for the Operation and Selection of Solid Waste Disposal Sites

As you may be aware, many of the hazardous wastes generated in Nova Scotia are disposed of in municipal landfills. Under the Department of Environment's Solid Waste Management Study Program, funds are provided to municipalities to assist in the identification of potential landfill sites, their design and operation. To assist the municipal sanitary landfill operator, the study identifies a list of "restricted" hazardous wastes which cannot be landfilled. Additionally, a list of "special wastes" is also prepared. Special wastes are those wastes which require assessment by our Department before disposal. Based on our assessment of established treatment/disposal techniques, a recommendation is made by our Department to the municipal operator.

. . . /2

In many cases, co-disposal of these "special wastes" in secure, sanitary landfills is acceptable, however, out of concern for local sensitivity, the local operator is given ultimate authority to make the final decision on whether the waste will be accepted at the facility.

I hope that this information will assist you in preparing guidelines.

Yours very truly,

Robert Bailey

Robert H. Bailey
Director
Policy, Planning & Coordination

RHB/rg
c.c. C. D. Carter, P. Eng.
A. L. Carroll, P. Eng.
D. Hynick, P. Eng.

Attachment

**Gouvernement du Québec**
**Ministère de l'Environnement**
**Direction générale de**
**l'amélioration et de**
**la restauration**
**des milieux atmosphérique**
**et terrestre**

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FEB 17 1982

M. M. DILLON LTD.
TORONTO OFFICE

Sainte-Foy, le 10 février 1982

FILE 9133-01

M.M. Dillon Ltd
Ingénieurs-Conseils
50, Holly Street
Toronto, Ontario
M4P 2G5

A l'att.: Mr. M.P. Scott, M. Sc.
Gérant de projets

Monsieur,

J'accuse réception de votre lettre du 26 janvier 1982 relativement au contrat que vous avez obtenu d'Environnement-Canada pour l'établissement de standards ou de directives sur l'enfouissement de déchets dangereux.

Je dois vous signaler que la réglementation au Québec défend l'enfouissement sanitaire de tout déchet toxique. De plus, nous croyons que, mis à part des déchets de faible toxicité, aucun résidu toxique ne doit être enfoui à moins d'être traité au préalable pour lui enlever son degré de toxicité. Enfin, aucun déchet liquide ne peut être enfoui de quelque façon que ce soit.

Par ailleurs, nous avons des normes quant à l'enfouissement de déchets industriels préalablement traités, normes qui sont très restrictives et qui se veulent assurer une protection optimum à long terme des nappes d'eau souterraines (une copie de ces normes est annexée à la présente).

J'espère que ces quelques informations sauront répondre à votre demande et je vous prie d'agréer l'expression de mes sentiments les meilleurs.

MG/mj

Michel Gauvin, ing. M. Sc.,

Directeur,
Gestion des Déchets Dangereux.

c.c.: Monsieur Fernand Leduc, Environnement-Canada.

RECEIVED
FEB 1982
M. M. DILLON LTD.
TORONTO OFFICE

MANITOBA
[illegible]
~~CORPORATE AFFAIRS AND ENVIRONMENT~~
Environmental Management Division
Box 7, Building 2
139 Tuxedo Avenue
Winnipeg, Manitoba
R3N 0H6

February 23, 1982.

|  |  |  |
|---|---|---|
| FILE | 9133-01 |  |
| ~~[illegible]~~ |  |  |
| ~~[illegible]~~ |  |  |
| File |  |  |

Mr. M.P. Scott, M.Sc., M.C.I.C.,
Project Manager,
Dillon Consulting Engineers
and Planners,
Box 219, Station K,
Toronto, Ontario.
M4P 2G5

Dear Mr. Scott:

Re: Guidelines for Landfilling of Hazardous Wastes

Thank you for your letter of January 26, 1982, and accompanying terms of reference for the above mentioned project.

Although hinted at in your letter and the terms of reference, it is not entirely clear to me whether the guidelines are expected to address siting parameters. If this is the case, I would suggest the following parameters be considered.

(1) Physical Criteria:

- geology
- groundwater
- seismic risk
- climate
- flood prone areas

(2) Land Use Criteria:

- recreation
- agriculture
- waterfowl
- ungulates
- forestry
- crown lands

...../2

Re: Guidelines for Landfilling of
Hazardous Wastes -- Continued

(3) Economics/Transportation:

- proximity to generators
- established transportation routes - rail, road.

If the terms of reference are to be limited to the technical aspects of design and operation, then I feel they are adequate. We are prepared to provide detailed comments after receipt of the draft guidelines.

For your information, I am attaching copies of:

- Waste Disposal Ground Regulation;
- Hazardous Materials Regulation;
- Guidelines for the Disposal of Asbestos.

Yours very truly,

W. George Bowen

W. George Bowen,
Assistant Deputy Minister.

Attachments.

File 9133-01

Alberta
ENVIRONMENT

Environmental Protection Services
Pollution Control Division
Waste Management Branch

403/427-5868
Telex 037-2006 TWX 610-831-2636
Oxbridge Place
9820 - 106 Street
Edmonton, Alberta, Canada
T5K 2J6

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M. DILLON LTD.
ONTO OFFICE

February 23, 1982

M. M. Dillon Limited
Box 219
Station F
Toronto, Ontario
M4P 2G5

ATTENTION: Mr. Wally Wells

Dear Mr. Wells:

In reference to the letter from M. Scott of January 26, I have reviewed the Terms of Reference for the Environment Canada study which aims at establishing guidelines for hazardous wastes handling.

The Terms of Reference include a very broad and comprehensive spectrum of analyses. Alberta is presently developing its own criteria along the same lines but at present, these are in a very preliminary stage and are not suitable for distribution.

Regarding provincial guidelines and/or regulations which may be pertinent to the study, I am forwarding a copy of the Hazardous Chemicals Act, 1978. This is the only piece of legislation which is available at the time. However, this is also due for amendment in the next few months.

I would be happy to discuss specific issues with you but I cannot provide a general input at this time.

Yours very truly,

K. J. Simpson, P.Eng.
Head, Waste Management Branch

GL/lb
Enclosure

to → J.A.H.
↓ file 9133-01
Hazardous Site
Guidelines

**New York State Department of Environmental Conservation**
**50 Wolf Road, Albany, New York 12233-0001**

**Robert F. Flacke**
**Commissioner**

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MAR 23 1982

M. M. DILLON LTD.
TORONTO OFFICE

February 8, 1982

Mr. Mike Scott
M.M. Dillon Ltd.
Box 219 - Station K
Toronto, Ontario Canada M4P2G5

Dear Mr. Scott:

Per our 1/25/82 telephone conversation, I am sending copies of our State regulations that address solid/hazardous waste identification, transportation, disposal, treatment and storage, also a copy of the CECOS International, Inc. Permit to Operate. The information provided should give you a good overview of our program and how it is applied.

If you have any questions or need clarification please feel free to contact me at (518) 457-3273.

Sincerely,

James N. Ludlam, P.E.
Senior Sanitary Engineer
Civil Technology Section
Bureau of Hazardous Waste Technology
Division of Solid Waste

JNL:djr

Enclosures

**Bayerisches Staatsministerium
für Landesentwicklung und Umweltfragen**

BStMLU · Postfach 81 01 40 · 8000 München 81

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MAR 17 1982
M. M. DILLON LTD.
TORONTO OFFICE

file
9133-01

Mister
M.P. Scott
Dillon Consulting Engineers
50 Holly Street

Toronto, Ontario
Canada

| Ihre Zeichen, Ihre Nachricht vom | Bitte bei Antwort angeben<br>Unser Zeichen | ☎ (0 89) 92 14 - 1<br>Durchwahl 92 14 - | München |
|---|---|---|---|
| | 8700-642-4896 | 2259 | 10.03.82 |

Guidelines for landfilling of Hazardous Wastes

Dear Mr. Scott,

thank you for your letter, dated 22.01.82. I send on to you some Information of our hazardous waste disposal system in Bavaria, comprising three central treatment facilities (chemophysical plants, incineration) and a network of gathering points with a combined disposal capacity of 350.000 tons per year. The residues of the treatment processes (dewatered, neutralized sludges, flyash, slag) and other solid wastes are deposited at the two special landfill sites in Schwabach and Gallenbach by spezial security conditions. While the landfill site of Schwabach ist located together with the treatment facilities, the Gallenbach site is dislocated (over 40 km) from the Ebenhausen treatment facilities in view of hydrogeological conditions. The Gallenbach site, the central facilities Ebenhausen and Schweinfurt as well the gathering points are run by the Company for disposal of hazardous waste ("Gesellschaft zur Beseitigung von Sondermüll in Bayern mbH").

The state-of-the-art is demonstrated by our landfill site Gallenbach which is in operation since 1975 (see my report from Octobre 1981).

We developed also guidelines for controlled Landfilling of Waste. However the guideline is prepared especially for domestic landfill sites, some points of the table of contents can be used for hazardous waste sites as well like

- site licensing procedure
- lines and leachate analysis and groundwater monitoring (see guideline WÜ 77).

I hope you get from my enclosures the right information for your task preparing canadian guidelines for hazardous waste.

If you like to visit the Gallenbach landfill, please contact me again.

Sincerly
I. A.

Franz Defregger
Baudirektor

Enclosure

## APPENDIX C

## DRAFT GUIDELINES FOR THE SELECTION OF CHEMICAL WASTE LANDFILLS - NOVA SCOTIA DEPARTMENT OF THE ENVIRONMENT

DRAFT

# NOVA SCOTIA DEPARTMENT OF THE ENVIRONMENT
# GUIDELINES FOR THE SELECTION OF CHEMICAL WASTE LANDFILLS

## A. GENERAL

A chemical waste landfill shall be approved by the Nova Scotia Department of the Environment pursuant to paragraph (c) of these guidelines. Such landfill shall meet all of the requirements specified in paragraph (b) of these guidelines, unless a waiver from these requirements is obtained pursuant to paragraph (c) 4 of the guidelines. In addition, the landfill shall meet any other requirements which may be prescribed pursuant to paragraph (c) 3 of these guidelines.

## B. TECHNICAL REQUIREMENTS

Requirements for chemical wastes landfills used for the disposal of chemicals that are potentially hazardous to the environment are as follows:

### 1. SOILS

The landfill site shall be located in thick relatively impermeable formations such as large area clay pans. Where this is not possible, the soil shall have a high clay and silt content with the following parameters:

(I) In-place soil thickness, 4 feet, or compacted soil liner thickness, 3 feet.

(II) Permeability (cm/sec), 1 x 10.$^{-7}$

(III) Percent soil passing No. 200 sieve, $\geqslant 30$

(IV) Liquid Limit, $\geqslant 30$

(V) Plasticity Index, $\geqslant 15$

(VI) Artificial Liner Thickness, $\geqslant 30$ mil.

Note: In the event that an artificial liner is used at a landfill site special precautions shall be taken to ensure that its integrity is maintained and that it is chemically compatible with the landfilled chemical. Soil underlining shall be provided as well as a soil cover.

## 2. HYDROLOGY

The bottom of the landfill shall be substantially above the historical high groundwater table. Floodplains, shorelines, and groundwater recharge areas shall be avoided. There shall be no hydraulic connection between the site and standing or flowing surface water. The site shall have monitoring wells and leachate collection and shall be at least fifty feet from the nearest groundwater.

## 3. FLOOD PROTECTION

(I) If the landfill site is below the 100-year floodwater elevation, the operator shall provide surface water diversion dykes around the perimeter of the landfill site with a minimum height equal to two feet above the 100-year floodwater elevation.

(II) If the landfill site is above the 100-year floodwater elevation, the operator shall provide diversion structures capable of diverting all of the surface water runoff from a 24-hour, 25-year storm.

## 4. TOPOGRAPHY

The landfill site shall be located in an area of low to moderate relief to minimize erosion and to help prevent landslides or slumping.

## 5. MONITORING SYSTEMS

### (I) Water Sampling

a) The ground and surface water from the disposal site area shall be sampled for use a baseline operations.

b) Defined water sources shall be sampled at least monthly when the landfill is being used for disposal operations.

c) Defined water sources shall be sampled indefinitely on a frequency of no less than once every six months after final closure of the disposal area.

(II) Groundwater Monitoring Wells

a) If underlying earth materials are homogeneous, impermeable, and uniformly sloping in one direction, only three sampling points shall be necessary. These three points shall be equally spaced on a line through the centre of the disposal area and extending from the area of the highest water table elevation to the area of the lowest water table elevation on the property.

b) All monitor wells shall be cased and the annular space between the monitor zone (zone of saturation) and the surface shall be completely backfilled or plugged with portland cement to effectively prevent percolation of surface water into the well bore. The well opening at the surface shall have a removable cap to provide access and to prevent entrance of rainfall or stormwater runoff. The well shall be pumped to remove the volume of liquid initially contained in the well before obtaining a sample for analysis. The discharge shall be treated to meet applicable provincial discharge objectives or recycled to the chemical waste landfill.

(III) Water Analysis

All samples shall be analyzed for those parameters required by the Nova Scotia Department of the Environment, and all data and records of the sampling and analysis shall be maintained for future reference. Sampling methods, analytical procedures and parameters to be covered shall be specified by the Nova Scotia Department of the Environment prior to a permit being issued to the operator of the proposed chemical waste landfill.

## 6. LEACHATE COLLECTION

A leachate collection monitoring system shall be installed beneath the chemical waste landfill. Leachate collection systems shall be monitored monthly for quantity and quality of leachate produced. The leachate should be either treated to acceptable limits for discharge in accordance with a provincial permit or disposed of by a provincially approved method. Water analysis shall be as provided in sub-paragraph (5) III of this paragraph. Acceptable leachate collection monitoring collection systems shall be one of the following designs unless a waiver is obtained pursuant to paragraph (c) 4 of these guidelines:

### (I) Simple Leachate Collection

This system consists of gravity flow drain field installed under the waste disposal facility liner. This design is recommended for use when semi-solid or leachable solid wastes are placed in a lined pit excavated into a relatively thick, unsaturated, homogeneous layer of low premeability soil.

### (II) Compound Leachate Collection

This system consists of a gravity flow drainfield installed under the waste disposal facility liner and above a secondary installed liner. This design is recommended for use when semi-liquid or leachable solid wastes are placed in a lined pit excavated into relatively permeable soil.

### (III) Suction Manometers

This system consists of a network of porous "stones" connected by hoses/tubing to a vaccum pump. The porous "stones" or suction manometers are installed along the sides and under the bottom of the waste disposal facility liner. This type of system works best when installed in relatively permeable unsaturated soil immediately adjacent to disposal facility bottom and/or sides.

## 7. CHEMICAL WASTE LANDFILL OPERATIONS

(I) Some chemicals with a high potential for a toxic leachate may have to be placed in the landfill in containers or articles. When this applies, such chemicals shall be placed in the landfill in a manner that will prevent damage to said containers or articles. Other wastes placed in the landfill that are not chemically compatible with these substances shall be segragated from them throughout the waste handling and disposal process.

(II) An operations plan shall be developed and submitted to the Nova Scotia Department of the Environment for approval as required in paragraph (c). This plan shall include detailed explanations of the procedures to be used for recordkeeping, excavation and backfilling, waste segregation burial coordinates, vehicle and equipment movement, use of roadways, leachate collection systems, sampling and monitoring procedures, monitoring wells, and security measures to protect against vandalism and unauthorized waste placement.

(III) Records shall be maintained for all chemicals disposal operations and shall include the three dimension burial coordinates for these chemicals.

## 8. SUPPORTING FACILITIES

(I) A six foot woven mesh fence, wall, or similar device shall be provided around the site to prevent unauthorized persons and animals from entering.

(II) Roads shall be maintained to and on the site which are adequate to operate and maintain the site without causing safety or nuisance problems or hazardous conditions.

(III) The site shall be operated and maintained in a manner to prevent safety problems or hazardous conditions resulting from spilled liquids and windblown materials.

## C. APPROVAL OF CHEMICAL WASTE LANDFILLS

Prior to the disposal of any chemicals in a chemical waste landfill the owner or operator of the landfill shall obtain written approval from the Minister of the Environment. Such approval shall be obtained in the following manner:

### 1. Initial Report

The owner or operator shall submit to the Nova Scotia Department of the Environment an initial report which contains:

(I) The location of the landfill.

(II) A detailed description of the landfill including general site plans and design drawings.

(III) An engineering report describing the manner in which the landfill complies with the requirements for chemical wastes landfills in paragraph (b) of these guidelines.

(IV) Sampling and monitoring equipment and facilities available.

(V) Expected waste volumes of chemicals.

(VI) General description fo waste materials that are expected to be disposed of in the landfill.

(VII) Landfill operations plan as required in paragraph (b) of these guidelines.

(VIII) Any local permits or approvals.

(IX) Any schedules or plans for complying with approval requirements of these guidelines.

### 2. OTHER INFORMATION

In addition to the information contained in the report described in sub-paragraph (1) of this section, the Nova Scotia Department of the Environment may require the owner or operator to submit such other information it finds to be reasonably necessary to determine whether a chemical waste landfill should be approved. such other information shall be restricted to the types of information in (1) I through (1) IX above.

### 3. CONTENTS OF APPROVAL

(I) Except as provided in sub-paragraph (4) of this paragraph the Nova Scotia Department of the Environment may not approve of chemical waste landfill for the disposal of chemicals unless he finds that the landfill meets all of the requirements of sub-paragraph (6) of this paragraph.

(II) In addition to the requirements of paragraph (b) of these guidelines, the Nova Scotia Department of the Environment may include in an approval such other requirements as it finds are necessary to ensure that operation of the chemical waste landfill does not present an unreasonable risk of injury to health or the environment from the chemicals. Such requirements may include a fixed period of time for which the approval is valid.

Such requirements may also include a stipulation that the operator of the chemical waste landfill report to the Nova Scotia Department of the Environment any instance of detection of the disposed chemical through any of the monitoring requirements of these guidelines.

### 4. WAIVERS

An owner or operator of a chemical waste landfill may submit evidence to the Nova Scotia Department of the Environment that operation of the landfill will not present an unreasonable risk of injury to health or the environment from chemicals being disposed, when one or more of the requirements of paragraph (b) of these guidelines are not met. On the basis of such evidence and any other available information, the Minister of the Environment may in his discretion find that any such requirements are not necessary to protect against such risk and may waive such requirements in any approval for that landfill. Such finding and waiver will be stated in writing and included as part of the approval.

## 5. PERSONS APPROVED

Any approval will designate persons who own and who are authorized to operate the chemical waste landfill, and will apply only to such persons.

## 6. FINAL APPROVAL

Approval of the chemical waste landfill will be in writing and will be signed by the Minister of the Environment. The approval will state all requirements applicable to that landfill.

# APPENDIX D

# RECOMMENDATIONS OF ENVIRONMENT COUNCIL OF ALBERTA - PUBLIC HEARINGS ON HAZARDOUS WASTE MANAGEMENT IN ALBERTA

## INTRODUCTION

The recommendations that follow represent Council's best judgement after public discussion and later detailed analysis of information received. Recommendations appear throughout the report where they arose in the course of its development. In this summary, they have been classified and brought together in groups of related subjects, so that they appear here in different order than in the main text. Although the recommendations are annotated, the reader is urged to refer to the original discussion in the report for the detailed background and analysis that led to them. Each recommendation is accompanied by a page reference to its source.

Two themes emerged from Council's examination of the problems of hazardous waste management in Alberta. The first is that there is agreement among industrialists, civil servants, and the public at large that a system of handling hazardous wastes safely is required in the Province of Alberta. This accompanies the realization that in the near future there will be substantial change in the nature of Alberta's industrial base and a growth in the volume and potential hazard of wastes generated.

The second theme that became apparent was that a Hazardous Waste Treatment Plant would not be a welcome neighbour. There is public uncertainty about the characteristics and qualities of such a plant, which is enough to make it unwanted.

At all stages in the development of this report, Council has taken the position that public safety is an overriding consideration. It is Council's judgement that the system proposed will not constitute a threat to human health or the environment. It is the intent that any treatment plant will be constructed under every reasonable precaution to ensure that it is safe and not a source of pollution itself.

## DEFINITION AND CLASSIFICATION

Council is of the opinion that well established and widely used terms be incorporated into Alberta regulations to allow easy comparison and exchange of information with other areas and jurisdictions. Such terms should be clear in their meaning and as precise as possible.

RECOMMENDATION 1: (p. 34)

**The term "hazardous waste" should be retained for the materials under consideration.**

RECOMMENDATION 2: (p. 39)

A simple, consistent substantive definition that can be used as a basis for statutory definition and sound management is as follows:

- Waste is any substance for which the owner/generator has no further use.
- Hazardous wastes are those wastes which, by their nature or quantity, may be detrimental to human health or the environment.

RECOMMENDATION 3: (p. 40)

A classification of types of hazardous waste can be used as the basis of a regulated management system and provide relief of regulatory burden. Hazardous wastes may be classified according to their perceived effects as follows:

1) Radioactive - to be referred to and disposed of by federal authorities
2) Explosive
3) Ignitable
4) Toxic
5) Reactive
6) Corrosive
7) Infectious
8) Sensitizer
9) Bioaccumulative
10) Mutagenic, Carcinogenic, Teratogenic
11) Miscellaneous.

### RECOMMENDATION 4: (p. 46)

A comprehensive schedule of waste substances and streams should accompany the definition and classification of hazardous wastes. The schedule should be amended as need arises.

## LEGISLATIVE CONTROL

Council sees distinct advantages accruing to the government and the people of Alberta with the development of unified regulations to control emissions to the total environment, that is, air, water, and land. Such "umbrella" legislation would focus the attention of Alberta Environment on its responsibility for protection of the total environment; it would give a single window both for pollution control and generator response; it would make possible more effective long-range planning; it would allow most effective use of government funds and personnel; it would serve to increase public belief in government intentions to protect health and the environment.

### RECOMMENDATION 5: (p. 164)

The regulation of all chemicals released to the environment, including hazardous wates, should be brought under the authority of a single Act, which would supersede the Alberta Clean Air Act (1971), Clean Water Act (1971), Hazardous Chemicals Act (1978), and Agricultural Chemicals Act (1970).

### RECOMMENDATION 6: (p. 160)

The Minister of the Environment should prepare, with public input, a long-range environmental plan, under Section 8 (1) of the Department of the Environment Act (1971).

RECOMMENDATION 7: (p. 159)

The Minister of the Environment should require the Environment Council of Alberta to hold public hearings on environmental standards and objectives. Hearings should be planned for the winter of 1983-84, to assist in the development of a long-range plan.

## ORGANIZATION AND FUNCTION

Several administrative criteria will govern the success of a hazardous waste management system, and hence determine the nature of its organization. The system must put safety as an overriding criterion, must be publicly acceptable and must accept all types of hazardous waste generated in Alberta (except radioactive wastes) regardless of cost, quantity, convenience, or hazard. Treatment charges should be uniform for identical wastes from all across the province. Charges should not place Alberta industries at a disadvantage with similar industries elsewhere, that is, subsidy will probably be necessary. The system must be managed responsibly and permanently. It must be at arm's length from the regulatory body.

RECOMMENDATION 8: (p. 116)

Consolidated Treatment Plants should be operated by an Alberta Crown Corporation.

RECOMMENDATION 9: (p. 200)

Legislation for the establishment of a Crown Corporation should be brought forward as soon as possible.

RECOMMENDATION 10: (p. 191)

A Research Division, under a Director of Research, should be established in the Crown Corporation at the earliest possible time. The Research Division will be important in establishing test and treatment facilities, cooperation with industry in the development and management of new processes and materials, and in advancing treatment techniques.

RECOMMENDATION 11: (p. 107)

Following the establishment of a Crown Corporation, the Government of the Province of Alberta should provide funding for capital facilities and the first two years of operating expenses. The financial exposure represents a one time charge of about $41 to $58 million.

RECOMMENDATION 12: (p. 194)

A sum equal to at least 10 percent of the capital and current budget of the Crown Corporation should be allotted annually, specifically for the support of research and development in the field of hazardous waste management.

RECOMMENDATION 13: (p. 81, p. 116)

Transportation from the generator to the treatment plant should be handled by private waste haulers. Route selection and timing should be based on distance, accident rate, traffic volume, and potential consequences of an accident.

## SYSTEM DESIGN AND SITE SELECTION

Examination and analysis of waste inventory, transport and other risks, public interest, and the nature of hazardous waste treatment has led Council to the opinion that, in order to maximize safety and increase public acceptability, the handling of hazardous wastes must be minimized, strict standards of treatment plant location and design must be applied, and the public must be involved in all stages of planning and operation.

RECOMMENDATION 14: (p. 85, p. 135)

The overriding consideration in system design and site selection should be safety for people and the environment.

RECOMMENDATION 15: (p. 77)

As a principle of design of a hazardous waste management system, the number of loading and unloading operations should be minimized.

RECOMMENDATION 16: (p. 81, p. 93)

Two Consolidated Treatment Plants should be established, one near Calgary and one near Edmonton.

RECOMMENDATION 17: (p. 81, p. 123)

Specifications:

a) Consolidated Treatment Plants, one near Calgary and another near Edmonton, should have highly sophisticated analytical laboratories and environmental monitoring systems, as well as facilities for:

1. physical chemical treatment
2. solidification
3. biological treatment
4. deep well disposal
5. secure long-term storage.

The near-Edmonton plant should be the site of high-temperature incineration. Each Consolidated Treatment Plant may be expected to develop special treatments as necessary.

Both Consolidated Treatment Plants should have the following facilities for the intake and storage (temporary and permanent) of hazardous wastes:

1. Weigh scales
2. Paved loading and unloading areas with drains to a sump
3. Secure storage areas with berms to contain the total volume of tanks enclosed
4. Secure, heated drum storage, with leakproof reinforced concrete floors

5. Secure landfill
6. Emergency response capability to react to spills, accidents or other mishaps both on and off the site
7. Secure fencing
8. Comprehensive first aid capability
9. Fully trained personnel for all activities.

b) Major Gathering Stations may be required at locations across Alberta as industrialization proceeds and hazardous waste quantities increase. Although not recommended for establishment now, if and when they are needed they should possess all the facilities for intake and temporary storage of hazardous wastes as outlined for the Consolidated Treatment Plants, as well as relatively simple laboratory facilities capable of determining parameters such as calorific value, percent moisture, common metals and anions, cyanides, and chlorine content. The decision to establish Major Gathering Stations should be left to the Crown Corporation.

c) Minor Gathering Stations are intended to provide temporary storage for materials of minor hazard, such as empty pesticide cans and waste lubricating oil. They would be very simple, fenced facilities, located at many points around the province, perhaps in association with regional landfills or existing sanitary landfills.

RECOMMENDATION 18: (p. 152)

The Minister of Environment should establish a Site Selection Committee under the Planning Act (1977) as soon as possible, to seek sites for Consolidated Treatment Plants. The Committee should comprise a majority of technical experts, with representation from Regional Planning Commissions, appropriate county or municipal councils, the Crown Corporation when formed, and the general public. The Department of the Environment, as the regulatory body, should not be represented on the Committee.

RECOMMENDATION 19: (p. 152)

The Site Selection Committee should be responsible for making detailed technical, social, and environmental studies that will lead to the choice of several potential sites for Consolidated Treatment Plants. Public hearings and frank, open and extensive public discussion should be sought, following which the Committee will arrive at its choices based upon a combination of technical criteria and public acceptability. Approval by government is then required.

RECOMMENDATION 20: (p. 152)

If it is clearly in the provincial interest to do so, the province must have the power to site facilities even if local municipal authorities object. The appropriate place for such authority is under the Department of the Environment Act administered by the Minister of Environment. However, the siting of a hazardous waste management facility over local government objections is considered to be too great a use of authority by a single ministry. Consequently the Minister of Environment should decide on appropriate sites, selected from the Site Selection Committee's list and present that recommendation to the Lieutenant-Governor-in-Council. The Lieutenant-Governor-in-Council should be the authority responsible for making siting decisions. This will ensure that if local concerns cannot be resolved, the necessary decisions will be made by the highest level of government.

RECOMMENDATION 21: (p. 135)

The following criteria should be considered by The Site Selection Committee for the establishment of a site for a Consolidated Treatment Plant.

a) Essential Criteria (no site should be considered if it fails to meet all of these criteria):

1) There must be a substantial degree of public acceptability as determined by assessment and evaluation of concerns expressed by residents in the vicinity of a site.
2) Minimum site size should be one section (256 ha). It would be highly desirable to acquire land up to about one mile (1.6 km) around the plant.
3) Flood plains should not be considered for sites.
4) A Consolidated Treatment Plant should be located on impermeable clay base. The clay should extend from the surface to at least 10 metres below the floor of the secure landfill.
5) Only land which is unsuitable for cereal crops or has severe limitations for crop production should be considered, that is, Canada Land Inventory Class 4-7.
6) Treatment facilities should not be located on rough terrain. No slopes subject to erosion or slumping can be included in the building site.
7) Only sites over formations suitable for deep well disposal should be considered.

b) Highly Desirable Criteria:

1) To minimize transportation risk, Consolidated Treatment Plants should be located close to the main sources of hazardous waste.
2) To minimize transportation costs, Consolidated Treatment Plants should be located close to the main hazardous waste sources, that is, within 100 km of Calgary and within 100 km of Edmonton.
3) Evaporation should substantially exceed precipitation on an annual basis.
4) A water supply should be close by.
5) A site should be well removed from environmentally sensitive areas.
6) A site should be in the least populated part of any area under consideration.

c) **Desirable Criteria:**

1) A site should be within commuting distance of a town.
2) Preference should be given to a site close to a primary or secondary road and a rail line.
3) Proximity to an adequate power line would be desirable.
4) Crown Land is preferable for the development of a site for a Consolidated Treatment Plant.

d) Other Criteria:

1) A site should not be located to conflict with high recreational values.
2) The presence of an industrial zone would be useful, but not mandatory, in siting a facility.

RECOMMENDATION 22: (p. 81)

There should be legislation passed immediately to require the reporting to Alberta Environment of any spill of hazardous waste or dangerous goods in excess of 50 litres. For certain difficult wastes, such as PCBs, a spill of any size should be reported.

RECOMMENDATION 23: (p. 201)

Kinetic Contaminants Canada Limited (KCCL) is now providing a safe, effective storage for PCB wastes in the province. Until a suitable technology for the disposal of PCBs has been identified and established, KCCL should continue to store that waste. When a method is approved, the disposal of the PCBs acquired by KCCL should be arranged between the Crown Corporation and KCCL. The Crown Corporation should also offer to acquire the PCB storage facilities of KCCL, with appropriate compensation.

## TREATMENT

For the hazardous wastes generated, treatment and disposal will take many forms; thermal, physical-chemical, biological, solidification, secure landfill, long-term storage, and combinations of these. The design of a Consolidated Treatment Plant will require great technical skill, expertse and ingenuity. Chapter 5 and Appendix 4 of this report deal with suggested treatment methods.

### RECOMMENDATION 24: (p. 94)

To provide a broad and general framework within which to consider the problem of hazardous waste, the following preferential hierarchy of action is proposed:

1) Do not generate hazardous waste.
2) Recycle or reuse hazardous waste.
3) Treat hazardous waste at the point of generation.
4) Treat hazardous waste at a Consolidated Treatment Plant.

### RECOMMENDATION 25: (p. 107)

The hazardous waste management system should be designed to treat about 120,000 tonnes/year. About 60,000 tonnes of this capacity may be for thermal incineration. This incineration capacity should be phased, beginning with one 30,000 tonne/year rotary kiln at a near-Edmonton site.

### RECOMMENDATION 26: (p. 264)

Energy for incinerators, over and above that provided by the material being incinerated, should be provided by waste oil that is surplus to recycling capacity. If waste oil is not available, coal should be used if possible.

### RECOMMENDATION 27: (p. 60)

Deep well injection should be used only for the disposal of hazardous wastes that would be suitable for discharge to surface waters after reasonable dilution.

## LICENSING

**The management of hazardous wastes will require a comprehensive licensing and regulatory program. The program must address waste generation, treatment, disposal, and transport. Responsibility for the program should lie with the Environmental Protection Services of Alberta Environment. There should not be a fee for the administrative procedures.**

RECOMMENDATION 28: (p. 164)

Existing producers of hazardous waste should obtain a registration number and a permit to produce their wastes, and report upon the volume and type of waste produced at each plant site. Future applicants should, in addition, provide details of waste stream components. Annual public reports should be filed with Alberta Environment on waste types, volume, and method of disposal used. Unless otherwise stated, licences should expire after five years. Renewal would require a comprehensive review of the generator's waste management practices.

RECOMMENDATION 29: (p. 165)

All treatment, storage, and disposal facilities, whether off site (for example, the Consolidated Treatment Plant) or on site, should be licensed, regulated, and controlled to the same standards. Licences should expire after five years; renewal would follow satisfactory inspection of facilities and improvement of techniques and controls as warranted. The facilities should prepare public reports containing information on wastes received, wastes treated, wastes stored, wastes shipped, and effluent or emission discharges.

RECOMMENDATION 30: (p. 168)

**On-site landfilling of materials should be eliminated whenever possible. Where required, it should be done by special permit only. Such landfills should be carefully regulated, mapped, and monitored. Developments which could affect reclaimed landfills should be fully regulated.**

RECOMMENDATION 31: (p. 80)

Hazardous waste transporters should require licensing, conditional upon meeting standards for washing facilities, fire suppression, financial stability, liability bonding, and design of transfer or storage areas under the company's control.

RECOMMENDATION 32: (p. 81)

Vehicles for the transport of hazardous waste should require special licences. Such vehicles should meet safety standards, including provisions of items such as safety valves and other design features to reduce spills in case of accident; radios, flashing lights, portable breathing apparatus, and protective clothing. There should be semi-annual inspection and defective vehicles must be removed from the road.

RECOMMENDATION 33: (p. 80)

Drivers of hazardous waste vehicles should be specially trained in emergency response procedures, spill and accident avoidance, properties and hazards of different waste types, and equipment operation and maintenance.

RECOMMENDATION 34: (p. 169)

Owners and operators of currently active hazardous waste storage areas or landfills should be required to register. Such registration will assist in the establishment of an accurate inventory. Until the proposed hazardous waste management system is in operation, the use of currently active storage areas or landfills will have to continue, even if inadequate to the proposed standards. Registration should incur no penalty and a new Act should not be enforced retroactively. Remedial action on monitoring would be at the expense of the Environmental Trust Fund (Recommendation 47).

## MANIFEST SYSTEM

A manifest system would have as its objectives:

**a) The development of an inventory of type, quantity and location of hazardous waste streams.**

**b) Control of the disposal of hazardous wastes.**

**c) Assistance in the safe handling and transport of hazardous wastes by controlling procedures, labelling, vehicle types, routes and contingency plans.**

**d) Identification of problem areas for enforcement agencies.**

**Ideally, there should be a common manifest system for all areas bordering on Alberta with which Alberta has substantial trade and communication. That would reduce the uncontrolled passage of wastes into and out of Alberta.**

RECOMMENDATION 35: (p. 173)

The following regulatory controls for a manifest system are recommended:

1) The Government of Alberta should design and implement a comprehensive computerized system for monitoring and controlling hazardous waste transport and disposal.
2) A manifest document should be designed and issued by the Government of Alberta for all hazardous waste in transit. Appropriate copies should accompany hazardous wastes being transported.
3) Process waste streams and hazardous substances should be scheduled by name to enable generators to recognize their responsibilities.

4) Generators, carriers, and treatment, storage and disposal facilities should be licensed and uniquely coded. The code would be used on the manifest form for identification and inventory.
5) Penalties for non-compliance or misrepresentation should be substantial, so that compliance with the regulations is economically more attractive than is violation.

RECOMMENDATION 36: (p. 175)

**Details of a manifest should include:**

a) Section 1. Generator:

1. Standard U.N. emergency spill response code.
2. Generator information (company name, name of the plant site, address, generator licence number, 24-hour emergency telephone number).
3. Waste classification and its hazard level.
4. Chemical components, including concentration in percent, parts per million, or mg per litre.
5. Information about containers used for shipment.
6. Special handling procedures and emergency response information.
7. Signature of an authorized agent of the generator.

b) Section 2. Transporter:

1. Transporter information such as name, address, licence number, 24-hour emergency telephone number.
2. Unit number of vehicle and operator's licence number.
3. Date and time of pickup by transporter.
4. Signature of an authorized agent of the transporter.

c) Section 3. Treatment, Storage or Disposal Facility:

1. Facility information (name, address, licence number, 24-hour emergency telephone number).
2. Amount and type of waste received and tested.
3. Date of acceptance.
4. Fees, charges or payment made for acceptance.
5. Treatment applied to waste.
6. Method of final disposal.
7. Disposal date.
8. Signature of authorized agent of the facility.

RECOMMENDATION 37: (p. 177)

Responsibility for the hazardous waste and liability for mishaps with it would lie with the appropriate section of the manifest, that is, generator, transporter, or treatment facility, whichever had the waste in hand. The only exception would be in the case of misrepresentation of the material by the previous handler.

RECOMMENDATION 38: (p. 181)

Legal actions related to liability due to hazardous waste problems should be given generous time limits, because it is often very difficult to determine when a problem exists and when it commenced.

## FEES

It is not intended that the proposed hazardous waste management system totally support itself by means of fees levied. Several principles militate against it. Generators of small quantities of waste must not be discouraged from using the system. Generators distant from Consolidated Treatment Plants must not be penalized by their location. Industrial activities must not be put at competitive disadvantage by the imposition of exorbitant costs.

RECOMMENDATION 39: (p. 98, p. 108)

Every generator should be allowed free access to the hazardous waste management system for the first 2,000 kg of hazardous wastes treated each year. This free service should be charged to government by the Crown Corporation and likely represents about $0.5 million/year.

RECOMMENDATION 40: (p. 94, p. 108)

The fee for treatment should depend upon the treatment cost for that particular waste. After a number of years the treatment cost should include the transportation throughout Alberta. Until that time is reached, transportation costs should be billed to the Provincial Government by the Crown Corporation. The transportation costs represent an estimated expenditure of $0.75 million/year.

RECOMMENDATION 41: (p. 105)

The average charge for treating waste may be about $100 (1980 $ Canadian), according to experience elsewhere. Weighted average charges should not exceed that amount, if an economic disadvantage is not to be placed on Alberta industry.

## REGULATION

RECOMMENDATION 42: (p. 160, p. 186)

Primary responsibility for the regulation of a hazardous waste management system should rest with the Environmental Protection Services of Alberta Environment. However, certain jurisdictional relationships should be maintained or developed:

a) Deep well disposal should continue to be regulated directly by the Energy Resources Conservation Board (ERCB) in consultation with Alberta Environment.

b) Sump fluid disposal should be reviewed but continue to be regulated jointly by the ERCB, Alberta Energy and Natural Resources, and Alberta Environment.

c) The standards for transportation of hazardous wastes should be developed jointly by Alberta Transportation and Alberta Environment. Alberta Transportation Weigh Stations could be used to spot check compliance with regulations.

d) Public health responsibilities for regulating municipal landfills should be transferred to Environmental Protection Services, Alberta Environment. Concurrently, the manpower now allocated in the public health field to regulation of landfills should be reassigned to a broader hazardous waste management program administered by Alberta Environment.

RECOMMENDATION 43: (p. 194)

Research into regulatory matters will be needed. Alberta Environment should expect to support research into the development of standards for hazardous waste management, environmental monitoring, and the regulatory and legal aspects of the disposal of hazardous wastes.

## ENFORCEMENT

There must be public confidence in the level of protection that Alberta's environment receives. Prompt and appropriate enforcement of regulations is vital to that confidence.

RECOMMENDATION 44: (p. 183)

The following elements of an enforcement program are recommended:

a) An enforcement staff should be created by legislation, with a clear description of its responsibilities.
b) Authority of enforcement staff for entry, search, seizure, preservation of evidence, arrest, issuance of lawful orders, general performance of its duties, and so on, should be defined in legislation.
c) The legislation should place special onus on enforcement staff to carry out their duties.

## INTERGOVERNMENTAL AGREEMENTS

RECOMMENDATION 45: (p. 23, p. 173)

The Province of Alberta should enter into agreement with the Provinces of British Columbia, Saskatchewan and Manitoba, and with the Government of Canada under the aegis of the Canadian Council of Resource and Environment Ministers, for the regulation of inter-provincial movement of hazardous wastes.

RECOMMENDATION 46: (p. 203)

A body, similar to the Prairie Provinces Water Board, should be developed for the interjurisdictional administration of hazardous wastes.

## ENVIRONMENTAL TRUST FUND

It should improve public and industrial confidence if a mechanism exists whereby there can be quick response to acute or newly found incidents with hazardous waste.

RECOMMENDATION 47: (p. 179)

There should be established an Environmental Trust Fund, initially capitalized by the Province of Alberta, but later supplemented by litigation against responsible parties, assessment of penalties, and through fees and taxes levied against products whose manufacture generates substantial quantities of hazardous waste. The fund would be used to clean up spills, reclaim abandoned sites, reimburse for demonstrated devaluation of property, assist industry in the event of serious and unexpected hazard, and so on.

## TARGET DATES

RECOMMENDATION 48: (p. 200)

A manifest system should be developed and put into operation as soon as possible, to begin the establishment of a realistic inventory.

RECOMMENDATION 49: (p. 201)

A target date for the operation of a full-scale hazardous waste management system should be 1985.

RECOMMENDATION 50: (p. 202)

An "umbrella" environmental protection act should be in place by 1985.

RECOMMENDATION 51: (p. 21)

Council recommends that the Department of Social Service and Community Health and the Department of Environment immediately implement the recommendations of the McCoy (1980) report.

The Council wishes respectfully to place these recommendations before you.

**Environment Council of Alberta**

Panel on
Hazardous Waste Management in Alberta

J. R. Nursall, Chairman

A. D. Crerar, Vice-Chairman

Peter. A. Adie

P. A. Adie, Member

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# APPENDIX E
# GUIDELINE FOR "CONTROLLED LANDFILLING OF WASTE"
# - WEST GERMAN FEDERAL ENVIRONMENTAL AGENCY

Umweltbundesamt
Federal Environmental Agency
December 1981

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# Guideline

# "Controlled Landfilling of Waste"

## Merkblatt

Die geordnete Ablagerung von Abfällen
(Deponie-Merkblatt, Stand 1. September 1979)

Aufgestellt im Auftrag der Länderarbeitsgemeinschaft Abfall unter Mitarbeit des Umweltbundesamtes und des Verbandes Kommunaler Städtereinigungsbetriebe

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# 1. Introduction

## 1.1 General

Waste disposal facilities for controlled landfilling of wastes are termed landfill sites (Deponien) in this Guideline. The quideline covers landfill sites on which solely or predominantly solid residential wastes*) such as domestic refuse, bulk refuse and industrial wastes are deposited. For simplicity these landfill sites are designated as municipal landfills (Hausmülldeponien). Landfill sites destined exclusively for special-wastes or solely for one particular kind of waste ("special landfill sites (Sonderdeponien") are not covered by this guideline.

Controlled landfilling is a well established procedure for orderly disposal of waste. For residential wastes it is the only method of disposal which can be used alone since all other methods of dispósal and recycling require a landfill site as a supplementary system.

This quideline indicates how the legal requirements can be complied with as regards the construction, operation and closure of landfill sites. The measures required in individual cases can be determined only on a basis of knowledge of the local conditions.

## 1.2 Legal Bases

In the construction, operation and closure of landfill sites all those involved are responsible within their own spheres of operation for ensuring that the legal and administrative regulations and the orders issued pursuant to these regulations are complied with.

The following, in particular, should be noted:

- Disposal of Wastes Law, as promulgated on 5th January 1977 (Federal Law Gazette I, p. 41, amended p 288)
- Waste laws of the Laender
- Waster Resources Law, as promulgated on 16th October 1976 (Federal Law Gazette I, p. 3017), revised by Art. 69 of the Introductory Law for the Tax Code (EGAO) of 14th December 1976 (Federal Law Gazette I, p. 3341)
- Water laws of the Laender
- Federal Nature Conservation Law of 20th December 1976 (Federal Law Gazette I, p. 3574, amended 1977 p. 650)
- Nature and landscape conservation laws of the Laender

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*) "Informationsschrift Abfallarten", Länderarbeitsgemeinschaft Abfall. Published by Erich Schmidt Verlag, Berlin, Bielefeld, Genthiner Straße 30 G, D-1000 Berlin 30.
Reprinted in "Müll-Handbuch" Erich Schmidt Verlag, Berlin, Kennziffer 1110

- Law on protection against harmful environmental effects due to air pollution, noise, vibrations and similar processes (Federal Immission Protection Law) of 15th March 1974 (federal Law Gazette I, p. 721, 1193), last revised by Art. 45 of the Introductory Law for the Tax Code of 14th December 1976 (Federal Law Gazette I, p. 3341)

- Law to prevent and combat infections diseases of man (Federal Epidemic Law) of 18th July 1961 (Federal Law Gazette I, p. 1012, amended p. 1300), last revised by 7th Law on adjustment of benefits under the Federal Pensions Law of 9th June 1975 (Federal Law Gazette I, p. 1321).

The Disposal of Wastes Law provides, inter alia, that

- wastes are to be disposed of in such a way that the welfare of the public is not impaired (s. 2, Subs. 1),

- wastes may be treated, stored and disposed of on land only in plants or etablishments (waste disposal plants) specially licensed for the purpose (S. 4, Subs. 1),

- the Laender shall draw up waste disposal plans for their areas based on supralocal considerations (s. 6, Subs. 1),

- the official approval of the responsible authority is to be neccessary obtained for the construction and operation of fixed waste disposal plants as well as for any fundamental change to such a plant or its operation (S. 7, Subs. 1).

## 1.3 Site Selection

§ 6, Subs. 1 of the Disposal of Wastes Law provides that the waste disposal plans of the Laender are to specify suitable locations for waste disposal plants. Accordingly, this guideline does not contain any advice regarding the selection of the location for a land disposal site.

Where a waste disposal plan has not yet been drawn up the selection of a location for a landfill site should be coordinated with the authority responsible for the waste disposal plan and with the planning and consultation authority.

The final decision concerning the suitability of a location for a planned site always lies with the planning authority.

## 2. Site Licensing Procedure

### 2.1 General

In the planning stage, preliminary to the construction of waste disposal plants, the body responsible for the project should establish contact with the responsible authority as early as possible. The planning approval procedure is governed by §§ 21-29 of the Disposal of Wastes Law.

§ 21, Subs. 1 of the Disposal of Wastes Law provides that the body responsible for the project which is the subject of the planning application is to submit to the responsible authority the drawings and explanatory notes identifying the project, the reason for it and the properties and facilities affected by the project. The documentation must contain an comprehensive description of the project. The relevant DIN specifications are to be complied with in the presentation of the documents. The required number of copies of the documents to be submitted with the license application will be determined by the responsible authority.

### 2.2 Required Documents

In the absence of any specific requirement by the responsible authority, the following documents should accompany the application for planning approval for a landfill site:

- Explanatory report
- Design and dimensioning of facilities
- Planning documentation
- Expert reports

### 2.2.1 Explanatory Report

The explanatory report must contain the data and specifications necessary to permit an assessment of the project. These generally include specifications concerning:

1. Reason for the plant, tasks set and contractual stipulations
2. Site selection
3. Neighbourhood and affected area
4. Collection area; type, composition, quantity and origin of the wastes, including details of the type and scope of collection and transport to the plant.
5. Site conditions regarding orography, meteorology and water economy, e.g. position with respect to the receiving water, flood zones, etc.
6. Details of public and private drinking water supply plants in the area affected by the landfill site

7. Suitability of the subsoil from the geological and hydrological point of view
8. Development and establishment of the landfill site, including supply an disposal services with a description of the specific facilities
9. landfill volume and service life of the site
10. Availability of cover material
11. Equipment and personal (design of the overall plant and of individual plant components)
12. Description of the operation procedure and the measures relating to work hygiene and immission protection
13. Cost of the plant (capital and operating costs, including recultivation costs)
14. Present utilization of the site area
15. Recultivation during and after completion of landfill operation
16. Utilization after completion of landfill operation

In addition, the explanatory report should contain a table of content of all accompanying documents

### 2.2.2 Calculation and Dimensioning of Plant Components

1. Dimensioning of the water supply installations
2. Dimensioning of the wastewater disposal installations (volume, pollution, treatment, monitoring, transport on site sewage systems, hydraulic calculations)
3. Dimensioning of the systems for collection, treatment and transport of leachate
4. Dimensioning of the systems for collection and transport of the groundwater and surface water
5. Static calculations for structures
6. Evidence of soil mechanics (stability and settlement of the landfill-body and the subsoil).

### 2.2.3 Planning Documentation

1. Outline map, scale 1 : 100,000 to 1 : 200,000 showing the disposal area, the location and the supralocal traffic connections

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2. Outline map (topographical map), scale 1 : 10,000 to 1 : 50,000 showing the plant and local services (communications, water, sewerage, electricity) and the surrounding groundwater and surface water utilization.

3. Map, scale 1 : 1,000 to 1 : 5,000 showing the actual utilization of the surrounding land. A list of plots giving owners and occupiers and the Land Registry/Surveyor's Dept. designation of the plots should be attached.

4. Map, scale 1 : 1,000 to 1 : 5,000 with contour lines showing all installations and auxiliary plants (e.g. access, boundary fences, service buildings, water and electricity supply lines, telecommunications equipment, collection, treatment and transport of surface water and leachate, groundwater level compensation and groundwater flow direction). The inclusion of contours for the final planned state may also be useful.

5. Cross sections and longitudinal sections, scale 1 : 1,000 to 1 : 5,000 (scale of heights 1 : 100) of the landfill site and the wastebody for various operating states showing the highest measured groundwater table (m above M.S.L.) and the time of measurement as well as sectional plans (schedule of strata) and sections for access roads and hydraulic structures.

6. Constructional drawings, scale 1 : 50 to 1 : 200 (plans, sections and views).

7. Drainage plan for surface water, stratum water, leachate and wastewater in the individual sections

8. Operating plan (details of the position of tipping areas, protective berms and on site roads in the individual sections).

9. Accompanying landscape conservation plan (recultivation plan) with details of all measures during the operating period and of the final form of the waste body and later utilization of the site.
   To illustrate the plan it is advisable to include aerial photographs, models and representations in undistorted sections.

### 2.2.4 Expertise

Those generally required are:

- Geological and hydrological report specifying subsoil and groundwater conditions, permeability of the subsoil, sealing measures required.

In individual cases it may also be necessary to provide:

- Meteorological study
- Emission/immission study
- Soil mechanics study
- Study of landfill lining.

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## 2.3 Type of Wastes to be Disposed of

In addition to the solid residential wastes

- domestic refuse
- industrial wastes similar to domestic refuse
- bulk refuse
- street sweepings
- market wastes
- garden and park refuse

a wide variety of wastes can generally be disposed of on municipal landfill sites. The decision regarding the type and quantity of wastes to be landfill lies with the respobsible authority. In this connection, the following factors in particular will have to be taken into account:

Location and efficiency of the landfill site

- Situation with regard to the water economy and geology of the location (Receiving water, subsoil)
- Climatological factors
- Availability of cover material
- Availability of landfill volume and extension potential
- Connection to the local and supralocal traffic network
- Mechanical equipment and personal
- Monitoring installations

Behaviour of the wastes during operation

- Resistance of the landfill body to traffic load
- Emissions (smell, dust, noise)
- Quantitative proportion to other wastes which act as a buffer
- Complications during operation

Long-term behaviour of wastes in the landfill body

- Treatment and disposal of the leachate
- pollution of the receiving water
- Chemical reactions and gas production
- Stability of the landfill body
- Settlement of the waste
- Recultivation of the landfill area

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In principle, an assessment of the wastes based on the factors listed may lead to the following decisions:

- The waste may be deposited on the landfill site without any special measures.
- The waste may be deposited on the landfill site only under special condistions and with special precautions.
- Owing to its type and/or quantity the waste must be taken to other waste disposal plants.

## 3. Establishment of landfill sites

### 3.1 Access Roads and on site roads

The road construction guidelines must be follwed as regards the access roads to the site. (Guidelines of the Research Associations on Highways: Guidelines on the construction of highway - RAL, and streets - RAST.)

The slope should not exceed 8%. Having regard to trouble-free winter operation, 10% gradients are permissible only in exceptional cases and for short distances.

The road with should permit trouble-free two way traffic and should therefore be at least 6.50 m. The edge of the access road should be marked by stones or posts.

The traffic requirements of other parties, such as for agricultural or forestry vehicles, must be borne in mind.

Any necessary signposting must comply with the Road Traffic Code.

As far as internal traffic is concerned, easily portable barriers and signposts must be used to ensure that delivery vehicles are guided without difficulty from the entrace control at the entry gate to the particular operation area. Traffic directions at the operation area are given by personal.

The refuse collection vehicles and private deliverers must pass along designated routes to specially identified operation areas on the site. The operation areas for mechanical unloading of vehicles and for manual unloading are separated from each other in order to speed up the unloading operation and the placement of the wastes as much as possible.

The roads on the landfill site must be passable in all weathers.

A separate access road free of crossroads leading to the garage should be provided for the steel wheeled compactor.

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Turning space must be provided outside the entrance gate and on the site itself in order to allow vehicles which are turned away or those wishing to make deliveries outside opening times to turn round.

## 3.2 Fencing

The site must be secured against access by unauthorised persons and against the incursion of game by a boundary fence. Where possible, the fence should be extended around the monitoring wells for groundwater, gas and leachate.

In many cases it is additionally advisable to place a suitable protective plantation outside the fence.

## 3.3 Tyre Cleaning

Care must be takten to ensure that traffic conditions on the public streets are not impaired by dirt carried from the site. Various possible methods are available:

a) Cleaning lane

Tyres will be satisfactorily cleaned if there is strip of road at least 300 m long, ideally inside the landfill site area, which can be driven along briskly. Frequent cleaning of the roads, depending on conditions, must be ensured. Separating strips can be used to restrict cleaning to the exit road.

b) Cleaning rollers

Two pairs of rollers are installed in a lay-by so that the vehicle stands with one axle at a time on the rollers. The rollers can be driven by a separate motor.

c) Tyre washing system

Tyre washing system should be arranged near the landfill body in the region of the exit lane. When soiling is heavy, spraying before and after is recommended. The system consists essentially of a 40-50 m long water trough with a water depth of approx. 0.10 to 0.15 m. An essential feature for satisfactory operation of the system is that the base of the trough should take the form of a grid through which the dirt which has been washed off can fall into a dirt sump. It should be noted that this system is of limited use in winter.

## 3.4 Entrance Area and Buildings

Logging of deliveries and the first, usually visual, inspection of the waste delivered takes place in the entrance area. In special cases samples are taken.

At the entrance to the site an information board should be placed to provide the public with information about the plant.

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The following information is required:

- Name of the plant
- Name and address of the body responsible for disposal
- Name and address of the operator
- Opening times

It is also appropriate to give the following information on the board

- Charges
- Completion of landfill operation
- Future use of the site.

The checking in of the vehicles takes time. For this reason a queuing space must be provided within the site before the check-in point. It may be useful to collect the waste from small deliveries in containers sited in the entrance area and accessible even outside opening times. Regardless of the design of the landfill site there must be a check-in building in the entrance area to provide space for the necessary clerical staff and inspectors and with a telephone line installed.

If circumstances permit, the main building can also be integrated with the check-in building.

In the case of larger plants it will be necessary to provide in the check-in building:

- Office with telephone line - depending on the arrangement of the weignbridge inclusive weighing room
- Laboratory - for quick analyses and storage of samples
- Instrument room
- WC

Changing rooms, washrooms and shower rooms are to be arranged so that clean and dirty areas are separated from each other (black - white system). An additional WC should ideally be provided for visitors.

In order to assess the water balance and emissions of a landfill, regular records of certain weather factors are required.

The installaltion for taking these measurements should be arranged in the vicinity of the operational building.

Workshops and buildings to accommodate the equipment should also ideally be near the operational building.

For the repair of equipment and machinery a pit and hoist are useful.

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The access roads and the floor of the building should be constructed so that the high surface pressure of the steel-wheeled compactors does not cause permanent damage (e.g. lay wearing planks).

In the check-in area there should be a stretch at least 18 m long which is straight and level where a weighbridge can be installed. The use of a weighbridge facilitates settlement with the users of the landfill and for planning purposes. A weighbridge with a capacity of at least 38 Mg, 16 to 18 m long and 3 m wide is required. Weighbridges with pressure pickups are particularly sturdy in operation. The measuring apparatus should be self-registering and self-recording and should ideally also record the type of waste, deliverer, date and time.

Automation of the weighing and recording operation speeds up checking-in and facilitates evaluation of the data for the purposes of stastistics. In particular in the case of large plants, electronic data storage is advisable.

It is necessary to weigh each vehicle twice or, if a master is available showing the unladen weight, only once. Experience shows that one weighbridge can handle up to 25 weighings per hour.

## 3.5 Construction of the Landfill Liner and Leachate Collection

### 3.5.1 Preliminary Remarks

If, when the location of a landfill site is to be selected, there are areas available with a natural subsoil which is adequately impervious these should ideally be preferred. In the event of other conditions prevailing at the location selected, special measures may be required to seal the landfill base (in relation to the site bottom and, in necessary, the site sides) if it is intended to prevent or restrict to a minimum the penetration of leachate from the landfill into the subsoil. The decision regarding the necessity for such measures is taken in each individual case by the responsible authority.

If the responsible authority decides on a landfill liner then the indications and recommendations given under item 3.5.2 should be noted.

When a landfill site is established the existing top soil should be removed and stored in such a way that it can be used later for recultivation.

Where the subsoil is naturally adequately impervious, it is advisable to rearrange the whole bottom of the site to a depth of 30 cm and to compact it according to soils engineering principles. Then the bottom of the site must be rolled smooth with the specified gradient. The rules relating to the placement of a sealing layer of natural materials (see item 3.5.3) apply similarly to the distribution of existing soil strata.

### 3.5.2 Design of Landfill Liners

Landfill liners are made either of

- natural materials, or
- synthetic materials.

Natural sealing materials are carefully placed and compacted sealing layers consisting of specially brought in soil materials with a sufficiently high clay and fine silt content.

A sealing layer which is placed in this way must be at least 60 cm thick all over. It must be compacted in layers so that a $k_f$ value of at least $1 \cdot 10^{-8}$ m/s in achieved. The surface must be rolled smooth with a slope towards the drains.

The completed sealing layer must be carefully protected against drying out, frost, erosion and mechanical damage. For this reason it may also be necessary to build up the layer section by section.

If the site has steep sides on which it is not possible to construct a continuous sealing layer, then as the landfill site is filled up with wastes and after removal of the top soil the sealing layer must be gradually extended with a slope towards the centre of the site.

Synthetic seals comprise in particular:

Prefabricated seals, e.g..

- in-situ seamed membranes made of suitable plastics
- in-situ seamed membranes made of suitable bitumens on a backing.

on site fabricated seals, e.g.

- layers made of mixtures of suitable existing or specially placed soil materials with synthetic resins, siliceous or other binders (motars) or swelling agents (bentonit)
- bitumen layers similar to those used in road building.

However, such seals and sealing layers must not be considered in isolation in the planning of a landfill liner. They are rather only one component, even if a very important one, of the overall sealing system shich is required.

The appropriate structure for a sealing system depends in each individual case chiefly on the type of seal, the conditions of the location and on the type and quantity of the wastes to be deposited. A sealing system which incorporates a synthetic seal as an integral component will, as a rule, consist of the following elements (in ascending order - see Figure 1):

- support or fine subgrade layer
- seal or sealing layer
- drain layer with or without drain system (see item 3.5.4)
- protective layer (to prevent damage to the sealing system by bulky or sharp items in the waste, and to prevent thermal stressing of components due to dump fires, etc.).

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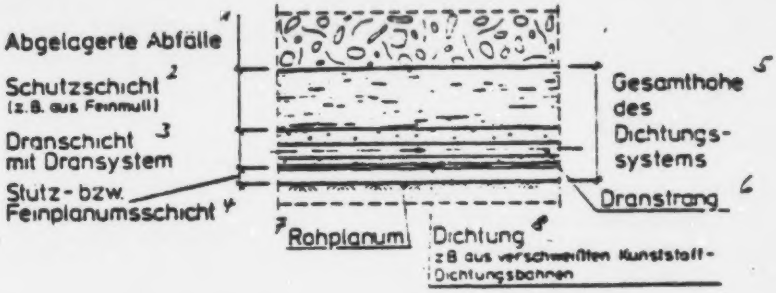
Abgelagerte Abfälle 1
Schutzschicht 2
(z.B. aus Feinmull)
Dranschicht 3
mit Dransystem
Stutz- bzw.
Feinplanumsschicht 4
Gesamthohe 5
des
Dichtungs-
systems
Dranstrang 6
7 Rohplanum
Dichtung 8
z.B aus verschweißten Kunststoff-
Dichtungsbahnen

1 landfilled waste
2 protection layer
3 drainlayer (coarse gravel and pipes)
4 supporting layer without sparp stone etc.
5 total heighth of liner system
6 drainpipe
7 upgraded soil
8 sealing, e.g. welded plastic membrane

Fig. 1 Sealing System for a landfill liner - Diagrammatic Cross Section

Since the state of technical knowledge and development in the field of landfill liner are still at a relatively early stage, it may be assumed that planning and design work on a liner will almost always presuppose a series of special tests. These may be tests concerning

- the soil mechanics characteristics of the existing subsoil or of the soil materials proposed for a sealing layer, and
- special questions relating to synthetic seals (e.g. determination of the material to be used for sealing sheets in view of the wastes to be deposited, determination of seaming techniques for the sheets).

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The conduct of such tests must be entrusted only to qualified specialists.

Even after completion of landfill and recultivation, the sealing system must remain in function until no more leachate requiring treatment is present.

### 3.5.3 Leachate Collection

Landfill site with a liner or sites situated on naturally impervious subsoil must be drained through a subsurface drain layer (if necessary, with additional drain system) located on the landfill bottom or on the seal or through a drain system in which a protective layer should be integrated. The resulting leachate must be discharged controlled.

The drain layer or the drain system must be constructed so that the leachate is led of quickly and reliably to prevent it from being banked up in the deposited wastes. This is of particular importance because.

- the elutriation from wastes lying in water is greatly increased and the treatment of the leachate is thus made more complicated and expensive, and
- due to banked up leachate the hydrostatic pressure head over the seal and consequently all the resulting potential risks to the subsoil are increased.

The following possibillties may be considered for the construction of the subsurface drain layer or the drain system:

1. Conventional drain system, integrated in a protective layer made of less permeable (fine-grained) materials.

   The drain system consists mainly of the branch drains and the main collector drains (auxiliary and trunk mains) as well as the inspection shafts and manholes. A drain system such as this is required since a protective layer consisting of fine-grained materials will not guarantee adequate drainage of the landfill bottom. It will frequently be useful to construct the main drains so that they can also accept water. A protective layer which works also as drain system may be considered in particular for natural seals.

2. Subsurface drain layer made of highly permeable (coarse-grained) soil materials (filter layer),

   a) without additional branch drain pipes
   b) with additional branch drain pipes.

   Branch drain pipes can increase the efficiency of the filter layer. They need not necessarily take the form of perforated piping; seepage trenches, amongst other things, also provide an appropriate solution.

   The leachate is accepted by the filter layer and is then fed to a single or to several main collector drains. It is the function of the main collector drains to lead the leachate out of the region of the bottom of the landfill and away. It may be necessary to arrange inspection shafts or manholes along the route of the main collector drains.

   The subsurface drain pipes must be designed on hydraulic and static principles.

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The minimum nominal diameter should be 100 mm. A minimum slope of 1% should be aimed at. When selcting materials it should be remembered that the leachate may be corrosive to concrete.

The main collector drains should ideally run in straight lines without bends. Care must be taken that the position of the subsurface drains is not altered by the later landfill operation. When the first layer of waste is deposited, the compacting machine must not be used on the landfill bottom or immediately above it. It should always move on a layer of waste at least 2 m thick so that the soil pressure does not become too great and in order to prevent damage to the seal and drain system.

The subsurface drains must be packed in portative filter material. The minimum cover above the pipe summit must be 30 cm.

In order to counteract ferric encrustation of the drains, air should be excluded from the drains (e.g. by means of an air trap or by means of pipes with underwater outlets). If a conventional drain system is constructed the gravel or stone fill must be able to take over the function of the pipes in accepting the water in case the latter become choked. It is due to such chocking, in particular, that the long-term functional reliability of filter layers must be rated higher than that of conventional drain systems.

The inspection shafts should ideally be located outside the landfill body. The inspection shafts and collector shaft must be easily accessible and should permit flow measurements to be made and samples to be taken (see also item 3.9).

### 3.6 Diversion of Groundwater and Surface Water

It is important to keep groundwater and surface water away from the body of the landfill in order to minimize as far as is possible the amount of leachate which has to be treated.

Only in exceptional cases is a pipeline beneath the landfill bottom permissible. Any such pipe must be leak-proof, highly corrosion and wear resistant and designed to withstand a high degree of stress due to settlement and load.

The pipe should be man-sized to allow for inspection and repair work.

Inspection shafts in the region of the landfill body should be avoided. Water which is dicharged within the landfill area must be collected and piped away in leak-proof pipes.

Unpolluted surface water from filled sections of the fill should be collected by means of suitable drainage systems and discharged. It may possibly be discharged into ditches around the site.

The quality of the separately discharged groundwater and surface water should be regularly checked.

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## 3.7 Other Wastewater from the Site

Domestic sewage from the operational building must be disposed of according to sewage engineering principles.

Wastewater from machinery and tyre washing installations should be recycled via a mechanical cleaning system (sedimentation tank) with an oil trap (downflow baffle). The wastewater emanating from this circulation system should be disposed of according to the appropriate sewage engineering principles.

Unpolluted storm water from the consolidated areas in the landfill should be collected and discharged separately. Guidelines on the treatment of storm water should be observed.

## 3.8 Equipment and Staffing Requirement[*]

Satisfactory landfill operation requires adequate equipment with suitable machinery.

The minimum equipment for every landfill site is a steel wheeled compactor. In addition, there should be machines available for cleaning the on site roads, for fire and dust fighting and for earthworks.

Steel wheeled compactors should always be used for the placement of bulky wastes. With careful placement it is possible to pack domestic and bulk refuse with fewer cavities using steel-wheeled compactors than with track-laying vehicles. The high degree of compaction improves the passability of the site to vehicles, reduces settlement and the risk of fire and lessens infestation by pests and wind-drifting.

The number of machines and the capacity required depends on the volume of waste to be placed per day, the type of waste and the landfill operation.

When selecting the steel-wheeled compactors it should be noted that the capacity of the machine decreases as the proportion of bulk refuse increases. The machines should have a high ground clearance combined with underbody reinforcement and good cross-country mobility.

The cab should be air-conditioned and soundproofed. The cooling air fans should be protected by dust filters.

Crawler loaders or wheel loaders are used for earthwork on the landfill site and to transport inert covering material. Only on small sites can steel-wheeled compactors which have a loading shovel instead of a blade replace these machines. Sweeping machines are necessary to keep the on site roads and, if necessary, the acess roads clean. This prevents dust from being blown about in dry weather and accidents due to skidding in the wet.
With single-shift landfill operation a total of at least three men will be required for reception, logging and inspection, vehicle direction and operation of the placement machines as well as other work (see also Section 4.2).

The staff must be reliable and trained for the job.

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## 3.9 Landfill Gas

The generation of gas in the landfill body is attributable to microbic processes of degradation. In the light of the present state of knowledge they may be expected to last for many years.

The composition of the landfill gas varies. A methane content of 50-70% and a carbon dioxid content of 30-50% may be regarded as typical. Other components found in smaller quantities are hydrogen sulphide, ammonia and nitrogen.

Damage resulting from gas has been reported only in isolated cases. In individual cases landfill gas may have the following environmentally relevant effects:

- explosions and fires
- danger of suffocation due to lack of oxygen when it occurs in concentrated form in confined spaces
- odour
- plant growth damage.

Where the subsoil which is laterally adjacent to the landfill body is more permeable to gas than the cover material the gas may penetrate as far as distant structures (e.g. basements, pipelines).

In practice, landfill gas poses no danger at not covered sites as far as landfill operation is concerned since the gas can escape over the whole surface of the landfill site. Furthermore, the waste surface is colonised by microorganisms which wholly or partially break down the methane component.

In order to prevent damage due to landfill gas the following precautions should be taken:

- Spaces where the presence of gas must be expected, i.e. in particular leachate inspection and collection shafts, may be entered only after the oxygen content has been tested or with full breathing equipment. Having regard to the increased danger of explosion the relevant accident prevention regulations must be observed.
- The landfill should not be used for building development unless such a project may be considered perfectly safe as a result of investigations into the generation of gas or the takingof structural precautions.
- In particular in the case of an impervious final cover it may be necessary in individual cases to take special measures for selective gas collection and extraction in order to prevent damage to growth. In the light of the present state of knowledge, the following basic methods may be considered:
- gas probes which are driven into the body of the landfill after final covering,
- Gasextraction shafts and gas outlet systems which are built up or laid as the fill is gradually filled.

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For selectively collected gases the possibilities are burning off, piping away through bio-filters or, if appropriate, recycling.

## 3.10 Bench Marks for Surveying

Outside the area affected by landfilling surveying points should be set up the position of which is referable to the official grid. At least three bench marks are required.

The setting up bench marks for surveying also facilitates compliance with the plan of working and monitoring the site as regards settlement. In addition, the bench marks facilitate the arrangement of a placement grid.

## 4. Landfill Operation

### 4.1 General

The normal operation of a landfill site is characterised by placement of the wastes immediately on delivery. The crushing of wastes and controlled aerobic decomposition of crushed or otherwise homogenised wastes before compaction are occasional variants on this. Even after such preliminary treatment the wastes are in every case placed as densely as possible.

Other variations on landfill operation may arise, for example, when the waste arrives at the site in pretreated form - e.g. in the form of bales - or when the wastes delivered are transported to the operation area in special vehicles after passing through an transfer station at the landfill site.

The method of operation must be clearly regulated for the staff employed at the landfill by means of a directive. In accordance with the requirements imposed by the official approval notice, this directive must specify how the permitted types of waste are to be deposited on the landfill site and who is responsible for the individual tasks and inspection of the work.

In addition, it is necessary to have an order specifying the use of the landfill which lays down the rights and duties of deliverers of wastes.

Particular reference should be made to the fact that

- only the prescribed roads are to be used
- wastes may be unloaded at the points provided for the purpose only
- no sorting of wastes by unauthorised persons is permitted
- the instructions of the staff are to be followed.

Questions relating to liability should also be regulated in the order.

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## 4.2 Tasks of the Operating Staff

The operating staff is responsible for the orderly landfill operation in accordance with the directive. The relevant accident prevention regulations must be complied with. The plan of working on which the planning approval is based must be complied with.

The waste delivered must be inspected. Materials not acceptable for landfilling must be rejected and logged (see item 4.3). The wastes accepted should be recorded separately according to types of waste.

The operating staff must take particular care that no fires occur and that nuisances due to smell, noise, dust, waste paper and plagues of animals are avoided. A check must be kept to ensure that the fence is intact. Items deposited in contravention of the regulations in the access area and on adjoining pieces of land must be removed without delay. The weighbridges, the meteorological measuring station and, if there is one, the groundwater observation well must be maintained and looked after in accordance with the relevant specifications. The leachate should be analysed regularly (cf. item 4.9). The following data should be regularly recorded in a log book which is to be kept on the site:

- weather conditions, e.g. temperature, rainfall and wind direction
- results of inspections of the water piping installations, especially the intakes and outfalls of the fencing around the site and of the immediate vicinity to check for fly tipping
- results of the measurements and analyses of the leachate
- unusual occurrences, e.g. accidents, fires, mechanical breakdowns
- type and quantity of wastes delivered, deliverers, origin, date of acceptance, area in which it was deposited (cf. item 4.3). The types of waste should be designated using the waste codes in the Information Sheet on Types of Waste produced by the Joint "Land" Committee on Waste. An evidence book as prescribed by Section 11, Para. 2 or 3 can be kept as part of the log book. For landfills not yet eqipped with a weighbridge the quantity of waste delivered should be determinded by volume.
- emptying of the leachate tanks, including recording the discharged quantity
- recultivation measures, stating type and extent
- site area used per day
- use of personnel and machinery

## 4.3 Entrance - control

The acceptability of wastes for landfilling should be checked before they are delivered to the site.

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LAGA - Deponiemerkblatt (Landfill Guideline, Germany)

The direct inspections of the wastes delivered at the landfill site relate essentially to:

- the deliverer's trip tickets
- the weight of the waste
- inspection of the waste itself
  (for: colour, consistency, smell, mixture, packaging).

This involves a comparison between the actual appearance of the waste delivered and that expected on the basis of the declaration. In cases of doubt samples should be taken of the waste delivered.

These inspection measures should be carried out by the operating staff near the weighbridge and when the delivery vehicles are unloaded. These areas must be linked by a communication system (e.g. walky talkies).

If doubts arise as to the identity of the waste

- during the check-in inspection then acceptance must be refused and the refusal recorded,
- during unloading of the vehicle or placement of the waste then unloading or placement must be stopped, the unloaded or deposited waste secured (e.g. against rain and access by unauthorised persons) and a sample taken of the waste. The generator of the waste, the landfill operator and the body responsible for disposal are to be informed.

Details of the wastes delivered should be recorded in the log book (cf. Item 4.2).

## 4.4 Operation Techniques

### 4.4.1 Compaction of Solid Wastes

After delivery, reloading and/or preliminary treatment the wastes are placed as densely as possible.

Compaction is carried out with steel wheeled compactors and crawlers. For surface placement the wastes are spread out on the horizontal or sloping operating area and crushed, compressed and compacted by being passed over several times with the compactior. The compacted layer is not deeper than 30-50 cm.

In order at the same time to accommodate non-crushable bulky items and sludges it is sometimes appropriate to use the tipping edge method. This involves placing the solid residental wastes in layers of max. 2 m in such a way that they can be pushed over a so-called tipping edge from the alredy compacted part of the operating area. The solid residential wastes should be unloaded approximately 10 m before the tipping edge and crushed by beeing driven over several times before being pushed over the tipping edge. The resulting flank slope should, at least at the end of the working day, be compacted and covered.

The bulky items and sludges are unloaded at the foot of the tipping edge and covered over from above.

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LAGA - Deponiemerkblatt (Landfill Guideline, Germany)

Both the surface placement and the tipping edge method should be carried out in as small a space as possible, taking into account the vehicle movement required and the necessary area for adequate crushing and compaction. Both placement techniquex are diagrammatically illustrated in Fig.2. During placement it is also necessary to bear in mind the limitation of the leachate. This can be done, for example, by sectional placement and a downward slope of the surface towards the outside.

Even if, before landfilling, the wastes have been subjected to aerobic decomposition, placement is carried out with the use of steel wheelid compactors.

It is also possible to crush the wastes immediately before landfilling in stationary plants, possibly combined with simultaneous removal of scrap. A disadvantage is that it is difficult to prevent waste paper and plastic from blowing about. The advantages are that the cost of placing the waste is reduced and the delivery vehicles do not need to travel over the site. The cost is, however, higher than the use of a steel wheeled compactor.

### 4.4.2 Placement of Dewatered Sludges from Municipal Sewage Plants

The sludges which may be considered for landfilling are usually digested and aerobically stabilized sludges; raw sludges may be deposited if suitable measures are taken, e.g. during dewatering, to prevent odour. It is not as a rule necessary for the sludge to be rendered hygienic. In the light of the present state of knowledge, sludges with water contents of up to 65%* may be landfilled withourt restriction. The timing of sludge deliveries must be determined in agreement with the person responsible for the landfill operation and coordinated with the delivery of solid wastes, having regard to the type and volume of sludge involved.

The disposal of limited quantities of sludges with a higher water content may be permitted if

- the stability and passability of the fill to vehicles is not impaired, regard being had amongst other things to the quantitative proportion to the solid wastes, and
- controlled placement is assured, taking into account aesthetic and hygienic factors and the prevention of odours.

With a view to the stability of the landfill body, dewatered sludges should be deposited in areas away from slopes. During placement, continuous layers of sludge should be avoided. Sludges should not be deposited directly on the bottom of the landfill.

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* Determination of water content using S 2 of the German unit processes for water, sewage and sludge analysis,
Deutsche Einheitsverfahren für Wasser, Abwasser und Schlammuntersuchungen (DEV), Verlag Chemie GmbH, Weinheim (see p. 30)

LAGA - Deponiemerkblatt (Landfill Guideline, GErmany)

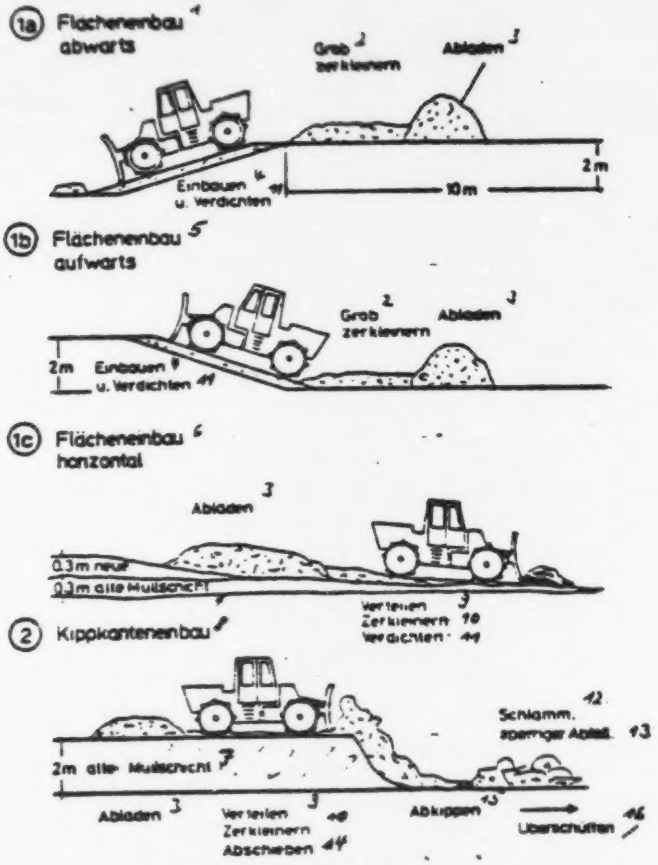
1a Flächeneinbau 1
abwarts
Grob 2
zerkleinern
Abladen 3
Einbauen 4
u. Verdichten 11
10m
2m
1b Flächeneinbau 5
aufwarts
Grob 2
zerkleinern
Abladen 3
2m
Einbauen 9
u. Verdichten 11
1c Flächeneinbau 6
horizontal
Abladen 3
0.3m neue
0.3m alte Müllschicht
Verteilen 9
Zerkleinern 10
Verdichten 11
2 Kippkanteneinbau 8
Schlamm. 12
sperriger Abfall 13
2m alte Müllschicht 7
Abladen 3
Verteilen 9
Zerkleinern
Abschieben 14
Abkippen 15
Überschütten 16

Abb. 2 Einbautechniken 17

1 compaction in thin layers, downhill
2 coarse crushing
3 unloading
4 placement and compaction
5 compaction in thin layers, uphill
6 compaction in thin layers, horizontal
7 previous layer of refuse
8 placement and compaction as shown in 2 m layers
9 distribution
10 crushing
11 compaction
12 sludge
13 bulky waste
14 pushing
15 unloading
16 cover with refuse
17 operation techniques

Fig. 2 Placement Techniques

### 4.4.3 Placement of Industrial Sludges

Where they are permissible for the landfill concerned, industrial sludges can be deposited in spadeable form in accordance with Section 4.4.1 and 4.4.2.

### 4.5 Daily Cover

At the end of each day's work the wastes must be deposited in such a way that nuisances to the neighbourhood caused by wind-blown waste paper, infestation by animals, fire and unsightliness of the operating areas are avoided.

The measures which may be necessary to meet these requirements are dependent on the location of the site and on the type of waste deposited and, in the case of extensive areas, also on the position of the operating areas vis-a-vis areas worthy of protection. If, during placement, a level and relatively firm surface is not achieved so that paper, plastic foil, etc. blow away, then it is impossible to dispense with daily covering.

The particular materials suitable for covering are those which do not blow away easily, from which no harmful substances are elutriated and which permit the passage of vehicle over the covered areas where this is required. Apart from excavated soil and building rubble which is not too coarse it is also possible to use other industrial wastes for covering material, the suitablility of which must if necessary first be determined by laboratory tests.

Where steel wheeled compactors are used to place the waste it may, under certain circumstances, be possible to despense with covering. This applies particularly to surface placement since with this method there is no loose slope. In addition, the lugs of the steel wheels serve to knead and bind the otherwise easily driftable waste.

Sloping level surface covered with clay or claylike soil permit on the one hand good surface storm-water runoff, but on the other hand lead to banking of water in the body of the landfill and to uncontrolled water outlets on the sloping sides and prvent the escape of gases if no additional structural measures are taken.

There are considerable operational difficulties for vehicles driving over layers of covers.

### 4.6 Control of Litter, Vectors and Fire

### 4.6.1 Litter Control

Protection of the neighbourhood from pieces of light plastic and paper beeing blown from the site must be achieved by careful placement of the wastes with compactors and/or additional daily covering.

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LAGA - Deponiemerkblatt (Landfill Guideline, Germany)

The problem of pieces being blown away during unloading of the wastes and during placement can be reduced by paper-catching screens. On some sites the boundary fence also acts as a paper-catching device. However, this has the disadvantage that the material must be gathered up afterwards.

A more satisfactory form of litter fence are paper-catching nets because the material blown into them falls down automatically when the wind drops.

When the wind changes direction and as the placement area advances, the litter nets have to be moved. A construction should therefore be selected which can be moved easily.

### 4.6.2 Birds and Vector Control

Flocks of birds, especially crows and gulls, around landfill sites are attributable to the supply of food available there in the form of organic waste. Experiments on municipal landfill sites have shown that the birds can be driven away for only short periods by scaring devices such as shot-firing systems, since they rapidly become used to such disturbances. Improvement can be made only be keeping the operation area of the landfill as small as possible. Daily covering of the operational area also yields advantages as far as prevention of infestation by birds is concerned.

Vector control must be left to officially licensed specialists. Evidence of regular vector control should be required.

### 4.6.3 Fire Prevention

Careful operation and thorough compaction help to counteract fires on landfill sites. The usual causes of occasional fires are:

- arson
- careless use of naked flame, and
- not wastes.

In general, the covering of fire points with cover materials e.g. soil has proved satisfactory. For this reason, it is important to keep a sufficient supply of covering material on the site. In the case of fires smouldering deep in the body of the landfill it may be necessary to dig out the core of the fire. The possibility of a temporary flaring up of the fire must then be accepted. Experience shows that only surface fires can be extinguished with water. The directive must lay down the necessary measures and specify the responsible persons.

## 4.7 Noise and Dust Control

Delivery vehicles and operation machinery represent sources of noise. This must be taken into account in planning a landfill in order, if necessary, to introduce appropriate noise reduction measures (noise protection berms and protective plantations). DIN 18 005 - noise protection in building construction - is decisive for the relevant considerations and preliminary measurements. Unacceptably high continuous noise levels rarely occur outside the landfill.

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LAGA - Deponiemerkblatt (Landfill Guideline, Germany)

Possible measures to protect the neighbourhood of a site surroundings from dust consist of moistening the site area and the on site roads as well as regular cleaning of the paved roads with sweeping machines in dry weather. Plantations around the edge of the site also contribute to the reduction of dust emissions.

### 4.8 Protective Berms

Depending on local requierements and in particular to protect residential and recreational areas, wind protection, noise protection and screening berms (protection berms) made of earth may be necessary. An adequate depth of cultivable soil must be placed on the outer slope. It is advantageous to lay out such protective berms and to plant them appropriately as long before starting landfill operation as possible.

For reasons of screening and noise protection the protective berms must always be higher than the operation area.
The stability of the protective berms must be ensured. In order to achieve optimum blending with the landscape

- the outer sides of the berms should be formed to correspond with the desired landfill surface shape after operation,
- the prevailing slopes in the surroundings should be taken as a guide,
- slopes steeper than 1:3 should be avoided, and
- in flat terrain gentle slopes (ideally less than 1:4) should be provided.

The topmost edge of the berms should be rounded-off and the foot of the slope flattened out; broken edges should generally be avoided.

The diversion of water, access to the site by traffic after completion of landfill operation and the later maintenance and repair of the installations are simplified if berms at least 3 m wide are constructed at height intervals of 5 to 8 m. The slope, the final height and the use to which the dump is later to be put are decisive factors affecting the arrangement of the berms.

### 4.9 Treatment of Leachate

#### 4.9.1 General

Before discharge into a water, the leachate must be treated in accordance with the discharge conditions.

If it is technically and economically possible to connect up to a sewage treatment plant of adequate size then this should certainly be done. If this facility is not available then the leachate must be collected in a leachate tank and transported to a suitable sewage treatment plant in tankers or treated in a suitable plant at the site. It is generally true that the treatment process is more stable when the leachate is mixed with municipal sewage than otherwise.

When siting a leachate tank it must be noted that there must be easy access for tankers. The tank must be fenced in to make it accident-proof. Signs must be posted to draw attention to the risk of explosions and the danger of climbing on the tank. The relevant accident prevention regulations should be referred to.

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LAGA - Deponiemerkblatt (Landfill Guideline, Germany)

The required capacity of the leachate tank ist determined by the volume of leachate produced and the frequency of collection. The minimum size should, however, be sufficient to hold a week's leachate.

Constant aeration of the leachate may be required in order to reduce the discharge of odour or to promote aerobic degradation of organic constituents. For this reason allowance must be made at the planning stage for subsequent installation of an open tank even where the leachate is piped in enclosed pipes to the sewage treatment plant.

### 4.9.2 Leachate Quantity and Composition

In the case of municipal landfill sites a mean annual leachate quantity - determined by rainfall - of approx. 0.01 to 0.1 l/s ha may be assumed. The daily leachate quantity may be up to 2.5 times the mean annual figure.

The type and quantity of the leachate constituents depend in particular on

- the subtances contained in the waste which are soluble in leachate,
- the physical conditions as well as the chemical and biological reactions which take place in the waste and in the leachate,
- the volume, distribution and retention time of the leachate in the deposited waste as well as the age of the landfill body.

The overall system represented by these usually interdependent processes is difficult to describe. A prognosis of the quality of the leachate is therefore only possible to a limited extent - datas from comparable existing landfill sites should be used as a basis. If this is not possible then under certain circumstances experiments should be carried out on an appropriate scale.

In operational sites leachate analyses have yielded result for essential parameters within the following ranges:

| | | | |
|---|---|---|---|
| pH value | 4 - | 9 | |
| COD | 2,000 - | 62,000 | (mg $O_2$/l) |
| $BOD_5$ | 60 - | 45,000 | (mg $O_2$/l) |
| Ammonium | 120 - | 3,200 | (mg $NH_4^+$/l) |
| Cloride | 750 - | 5,200 | (mg $Cl^-$/l) |
| Sulphate | 1 - | 1,600 | (mg $SO_4$-/l) |

Alkali metals and alkaline earth metals occur in high concentrations, and the concentrations of heavy metals occuring in leachate and in municipal sewage are of approximately the same order of magnitude.

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LAGA - Deponiemerkblatt (Landfill Guideline, Germany)

### 4.9.3 Treatment processes

For leachate treatment in installations at the site oxidation ponds and other biological treatment methods may be considered. Experiments have yielded decomposition rates of 95 to 99% for the $BOD_5$ and 20 to 50% for the COD. It should be noted that although the final $BOD_5$ figures were still up to 3,500 mg/l. These residual concentrations of organic substances which are not easily biochemically degradable can be reduced only by means of further purification processes (e.g. the use of precipitation processes).

### 4.9.4 Leachate Analyses

After starting landfill operation analysis of the leachate must begin without delay.

The extent of the analysis is laid down in the licensing document.

Simple leachate analyses can be carried out by the staff if both the technical qualifications of the staff and correct maintenance of the equipment (e.g. calibration of probes) can be quaranteed.

The analyses may cover in particular the following aspects

- discharge
- colour
- smell
- turbidity
- floating matter /smears
- suspended solids
- temperature
- ph value
- electrical conductivity

The relevant guidelines of the Joint "Land" Comittee on Waste (LAGA)*) should be followed.

### 4.10 Groundwater Monitoring

Observation wells should have pipe diameter (finished diameter) of at least 150 mm in order to permit the groundwater level to be measured and groundwater samples to be taken. The number, location and depth of the observation wells and their technical specifications must be determined in consultation with the technicall authorities. It must be possible to close off the well tops.

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*) Guidelines on procedure for physical and chemical analyses in connection with the disposal of wastes

- PN 1/75 - Taking of Water Samples
- UP 1/75 - Presentation of Results of Analyses of Water Samples and Eluates
- Wü /77 - Scope of Groundwater, Surface Water and Leachate Monitoring in the Area of Waste Disposal plants

Richtlinien der Länderarbeitsgemeinschaft Abfall
published by Erich Schmidt Verlag Berlin, Reprinted in "Müllhandbuch"

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To ensure the accuracy of the results at least one observation well should also be located upstream of the landfill.

Groundwater samples should also be taken and analysed before the landfill operation starts (zero samples).

The relevant LAGA guidelines (cf. Item 4.9.4) should be followed regarding the scope of analysis of the groundwater samples, the conduct of the sampling, the preparation of the sampling reports and the presentation of the results of the analysis.

## 5. Recultivation Measures

By recultivation is understood the blending of the landfill body into the surroundings and landscaping measures in prparation for the future use of the site area. On part areas the necessary work should be carried out even before and during the operation of the landfill and for the remainder immediately after completion of the landfill operation.

The relevant standards (DIN 18 300, 18 320, 18 915 to 18 919), memoranda and guidelines by the "Laender" must be complied with.

The measures to be taken should be laid down in an accompanying landscaping plan (recultivation plan) according to type, extent and cost and with regard to their timing relative to each other as part of the operational sequence. The consequent recultivation costs are part of the costs for landfilling.

When placing the last layer of waste in particular, the subsequent use to which the area is to be put and the type of recultivation measures which are to be later taken should be borne in mind.

Recultivation by covering with cultivable soil is the rule. Covering may be dispensed with if this is permitted by the proposed later use of the area. The same applies to the possible mixing of soil with the top layer of refuse.

Where covering is used the thickness of the layer of cultivable soil to be applied depends on the later use, in particular on the root space required. Subsoil and top soil should be placed so that continuous growth, or other intended later use, is possible. Account must here be taken of the interaction between the covering and the body of the landfill with regard to the gas and water economy and possible consequent impediments to plant growth.

The surface of the landfill site should be constructed and formed so that storm-water is largely diverted from the landfill body. A minimum slope of 3% should be aimed at.

The slopes should generally be planted with trees and sown with grass to provide effective protection against erosiom. Erosion and slipping must if necessary be prevented by stabilizing construction as per DIN 18 918.

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LAGA - Deponiemerkblatt (Landfill Guideline, Germany)

## 6. Long Term Care

After closure of the landfill the following measures for long-term care are still required:

- Maintenance of the leachate collection, discharge and treatment systems
- Discharge, treatment and monitoring of the leachate
- Maintenance of the surface run-off channel systems
- Maintenance of the groundwater monitoring wells and groundwater control system
- Maintenance of existing gas control systems
- Remedying of damage caused, for example, by erosion, slipping or uneven settlement
- Maintenance and upkeep of the vegetation.

If necessary, the financing and conduct of these measures should be quaranteed by the requirement that security should be provided.

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LAGA - Deponiemerkblatt (Landfill Guideline, Germany)

# APPENDIX F
# U.S. EPA CRITERIA FOR HAZARDOUS WASTES

# APPENDIX F
## U.S. EPA CRITERIA FOR HAZARDOUS WASTES

The U.S. EPA, in its proposed regulations has established definitions for hazardous waste characteristics in terms of ignitability, corrosivity, reactivity and EP toxicity.

### a) Ignitability

The intent of characterizing ignitability was to classify certain types of wastes which may pose hazards of fires during routine handling and disposal. Ignitability was defined as:

- liquids having a flash point of less than 60°C;
- non-liquids liable to cause fires through friction; spontaneous chemical change or absorption of moisture;
- ignitable compressed gases;
- oxidizers.

### b) Corrosivity

The corrosivity factor usually refers to liquids or semi-liquids. It has been defined as wastes having:

- a pH factor less than or equal to 2 or greater than or equal to 12.5;
- can corrode steel at a rate greater than 6.35 mm per year.

### c) Reactivity

The intent was to identify wastes which posed potential hazards during handling and disposal of the wastes especially considering operations at the landfill.

Reactive waste were defined as those wastes which:

- readily undergo violent chemical change;
- react violently with water or forms explosive mixtures with water;
- generate toxic fumes when mixed with water;
- are capable of explosive reaction when subjected to a strong initiating force;
- explode at normal temperatures and pressures.

### d) EP Toxicity

In characterizing the toxicity, primary consideration was given to ground water contamination. The EP (Extraction Procedure) test was designed to simulate leachate physical processes which occur in the landfill. Although the test procedure has been questioned, it is generally acknowledged that it is a fair evaluation of toxicity of various parameters for the purposes of classification of hazardous wastes.

A table showing the limits is given below.

## TABLE F-I

## MAXIMUM CONCENTRATION OF CONTAMINANTS FOR CHARACTERISTIC OF EP TOCITY

| EPA Hazardous Waste Number | Contaminant | Maximum Concentration (milligrams per litre) |
|---|---|---|
| D004 | Arsenic | 5.0 |
| D005 | Barium | 100.0 |
| D006 | Cadmium | 1.0 |
| D007 | Chromium | 5.0 |
| D008 | Lead | 5.0 |
| D009 | Mercury | 0.2 |
| D010 | Selenium | 1.0 |
| D011 | Silver | 5.0 |
| D012 | Endrin (1,2,3,4,10,10-hexachloro-1,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, endo-5,8-dimethano naphthalene. | 0.02 |
| D013 | Lindane (1,2,3,4,5,6-hexachloro-cyclohexane, gamma isomer | 0.4 |
| D014 | Methoxychlor (1,1,1-Trichloro-2,2-bis [p-methoxyphenyl]ethane). | 10.0 |
| D015 | Toxaphene ($C_{10}$,$H_{10}$,$Cl_8$, Technical chlorinated camphene, 67-69 per cent chlorine) | 0.5 |
| D016 | 2,4-D, (2,4-Dichlorophenoxyacetic acid). | 10.0 |
| D017 | 2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid). | 1.0 |

# APPENDIX G

# COCHRAN'S APPROXIMATION TO THE BEHRENS-FISHER STUDENTS' T-TEST

# APPENDIX G

# COCHRAN'S APPROXIMATION TO THE BEHRENS-FISHER STUDENTS' T-TEST

Using all the available background data ($n_b$ readings), calculate the background mean ($X_B$) and background variance ($S_b^2$). For the single monitoring well under investigation ($n_m$ reading), calculate the monitoring mean ($X_m$) and monitoring variance ($S_m^2$).

For any set of data ($X_1, X_2 \ldots . X_n$) the mean is calculated by:

$$\bar{X} = \frac{X_1 + X_2 \ldots + X_n}{n}$$

and the variance is calculated by:

$$S^2 = \frac{(X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 \ldots . + (X_n - \bar{X})^2}{n-1}$$

where "n" denotes the number of observations in the set of data.

The t-test uses these data summary measures to calculate a t-statistic (t*) and a comparison t-statistic ($t_c$). The t* values is compared to the $t_c$ value and a conclusion reached as to whether there has been a statiscally significant change in any indicator parameter.

The t-statistic for all parameters except pH and similar monitoring parameters is:

$$t^* = \frac{X_m - X_B}{\sqrt{\frac{S_m^2}{n_m} + \frac{S_B^2}{n_B}}}$$

If the value of this t-statistic is negative then there is no significant difference between the monitoring data and background data. It should be noted that significantly small negative values may be indicative of a failure of the assumption made for test validity or errors have been made in collecting the background data.

The t-statistic ($t_c$), against which t* will be compared, necessitates finding $t_B$ and $t_m$ from standard (one-tailed) tables where,

$t_b$ = t-tables with $(n_B-1)$ degrees of freedom, at the 0.05 level of significance.

$t_m$ = t-tables with $(n_m-1)$ degrees of freedom, at the 0.05 level of significance.

Finally, the special weightings $W_B$ and $W_m$ are defined as:

$$W = \frac{S_B^2}{n_B} \text{ and } W = \frac{S_m^2}{n_m}$$

and so the comparison t-statistic is:

$$t_c = \frac{W_B t_B + W_m t_m}{W_B + W_m}$$

The t-statistic ($t^*$) is now compared with the comparison t-statistic ($t_c$) using the following decision-rule:

> If $t^*$ is equal to or larger than $t_c$, then conclue that there most likely has been a significant increase in this specific parameter.
>
> If $t^*$ is less than $t_c$, then conclude that most likely there has not been a change in this specific parameter.

The t-statistic for testing pH and similar monitoring parameters is constructed in the same manner as previously described except the negative sign (if any) is discarded and the caveat concerning the negative value is ignored. The standard (two-tailed) tables are used in the construction $t_c$ for pH and similar monitoring parameters.

If $t^*$ is equal to or larger than $t_c$, then conclude that there most likely has been a significant increase (if the initial $t^*$ had been negative, this would imply a significant decrease). If $t^*$ is less than $t_c$ then conclude that there most likely has been no change.

A further discussion of the test may be found in Statistical Methods (6th Edition Section 4.14) by G.W. Snedecor and W.G. Cochran, or Principles and Procedures of Statistics (1st Edition, Section 5.8) by R.G.D. Steel and J.H. Torrie.

STANDARD T-TABLES 0.05 LEVEL OF SIGNIFICANCE

| Degrees of Freedom | t-values (one-tail) | t-values (two-tail) |
|---|---|---|
| 1 | 6.314 | 12.706 |
| 2 | 2.920 | 4.303 |
| 3 | 2.353 | 3.182 |
| 4 | 2.132 | 2.776 |
| 5 | 2.015 | 2.571 |
| 6 | 1.943 | 2.447 |
| 7 | 1.895 | 2.365 |
| 8 | 1.860 | 2.306 |
| 9 | 1.833 | 2.262 |
| 10 | 1.812 | 2.228 |
| 11 | 1.796 | 2.201 |
| 12 | 1.782 | 2.179 |
| 13 | 1.771 | 2.160 |
| 14 | 1.761 | 2.145 |
| 15 | 1.753 | 2.131 |
| 16 | 1.746 | 2.120 |
| 17 | 1.740 | 2.110 |
| 18 | 1.734 | 2.101 |
| 19 | 1.729 | 2.093 |
| 20 | 1.725 | 2.086 |
| 21 | 1.721 | 2.080 |
| 22 | 1.717 | 2.074 |
| 23 | 1.714 | 2.069 |
| 24 | 1.711 | 2.064 |
| 25 | 1.708 | 2.060 |
| 30 | 1.697 | 2.042 |
| 40 | 1.684 | 2.021 |

Adopted from Table III of "Statistical Tables for Biological, Agricultural and Medical Research" (1947, R.A. Fisher and F. Yates).

# APPENDIX H
# U.S. REGULATORY PROGRAMS FOR RESTRICTION OF LAND DISPOSAL OF HAZARDOUS WASTES

# APPENDIX H

# U.S. REGULATORY PROGRAMS FOR RESTRICTION OF LAND DISPOSAL OF HAZARDOUS WASTES

## A. California

In California a regulatory program is underway to phase out land disposal of certain high priority wastes. The approach adopted has been to identify waste constituents presenting the greatest risk to health and the environment, and identify alternative treatment technologies. The criteria for assessing risk were toxicity, persistence in the environment, ability to bio-accumulate, and mobility in the landfill environment. On this basis the high priority wastes chosen for phase out are:

- PCBs
- Pesticides
- Toxic metals
- Cyanides
- Halogenated organics
- Non-halogenated volatile organics

Concentration limits have been set for liquid wastes and the leachate from solids and sludges as follows:

1.

| Toxic Metals | Liquid Concentration (mg/L) | Extractable/Wet Waste Mass (mg/kg) |
|---|---|---|
| As | 50 | 5 |
| Be | 10 | 1 |
| Cd | 10 | 1 |
| Cu | 150 | 15 |
| Cr(vi) | 50 | 5 |
| Hg | 2 | 0.2 |
| Ni | 200 | 20 |
| Se | 10 | 1 |
| Ag | 50 | 5 |
| Te | 50 | 5 |
| Organic Pb | 13 | (liquids or sludges) |

2. Cyanide - ≯ 1000 mg/kg (wet weight)

3. Strong acids - pH ≮2

4. Halogenated organics - ≯ 1000 mg/kg

5. PCBs liquids - ≯ 7 mg/L except for spills

6. Other toxic wastes - classified as "extremely hazardous", defined as those wastes, "which if human exposure should occur, may likely result in death, disabling personal injury or illness".

## B. New York

In New York the current hazardous waste regulations allow no more than 15 per cent free liquid or air in wastes or containers to be landfilled. Certain hard pesticides and other toxic materials are also restricted including PCBs. Proposed legislation identifies three groups of high priority wastes that should be prohibited from disposal in landfills.

1. Materials containing the following specific chemical species, unless fixed in a low leach rate matrix, in excess of one-tenth of 1 per cent by weight measured prior to addition of any inert solid or liquid material which would reduce the concentration of the contaminants:

   - Aldicarb
   - Aldrin
   - Aluminum phosphide
   - Ammonium picrate
   - Arsenic Acid
   - Benzidine
   - Bix (chloromethyl) ether
   - Carbon disulfide
   - Cyanogen
   - Cyanogen chloride
   - Dieldrin
   - Endosulfan
   - Endrin
   - Heptachlor
   - Mercury fulminate
   - Nickel carbonyl
   - Nitroglycerine
   - Phosgene
   - Sodium azide
   - Tetranitromethane
   - Toxaphene
   - All soluble cyanide salts
   - Phorate (also for Disulfoton), or 0, 0-diethyl-S-(ethylthio), methyl - phosphorodithioate (Thime R), and disulfoton, or 0, 0-diethyl-S- (2-ethylthio), ethyl phosphorodithioate (Di-System R)

- Parathion (and Methyl parathion), or (O,-Odiethyl-O-p-ni-trophenylphosphorthioate, and methyl parathion, or O, O-dimethyl-O-p-nitrophenylphosphorothioate.
- Pentachlorophenol (PCP).

2. Specific waste types

- Bulk liquids including solvents
- Explosives
- Highly soluble metal salts
- Radioactive (in chemical waste landfills)
- Shock sensitive
- Pyrophoric
- Flash point less than 80°F.

3. Hazardous waste from specific sources:

- Waste water treatment sludge from the production of chlordane
- Filter solids from the filtration of hexachlorocyclopentadiene in the production of chlordane
- 2.6-dichlorophenol waste from the production of 2.4-D
- Heavy ends (still bottoms) from the purification column in the production of epichlorohydrin
- Waste water treatment sludge from the production of toxaphene
- Untreated process waste water from the production of toxaphene
- Vacuum stripper discharge from the chlordane chlorinator in the production of chlordane.

An amendment is also under consideration to exclude "waste incapable of maintaining its physical dimensions within 5 per cent and its form under expected disposal conditions of compressive load of 50 psi in landfills permitted to receive hazardous wastes".

## C. Minnesota

Proposed legislation in Minnesota considers four classes of hazardous wastes that should be excluded from landfills, based essentially on criteria for recyclability and leachability.

- Class A hazardous wastes designated as recyclable.
- Class A hazardous wastes which do not exhibit low leachability.
- Class B hazardous wastes designated as recyclable and which do not exhibit low leachability.
- Waste containing free liquids.

Class A Hazardous wastes are defined as:

- Ignitable, reactive or corrosive wastes.
- Those wastes containing specific carcinogens (see list at end of this Appendix).
- Those wastes containing 100 or more times the EP toxicity limit presented in Table H-1 of this appendix, when tested using an appropriate leach test. (This is an extended version of EPA's criteria for EP toxicity.)
- Wastes referended in a list of 200 chemicals based on the EPA hazardous waste listing).

Class B hazardous wasts are defined as:

- Those wastes containing 10 to 100 times the EP toxicity limit presented in Table H-1 of this appendix.
- By reference to EPA lists of wastes from specific and non-specific sources.
- By reference to a further listing, which essentially encompasses all other wastes defined as hazardous by EPA.

Recyclable wastes are designated as follows:

- Commercial chemical products including unused laboratory grade products.

- Solvents, used or contaminated, including:

    - halogenated solvents such as trichloroethane, perchlorethylene, methylene dichloride, chloroform, carbon tetrachloride, and freons;

    - oxygenated solvents such as acetone, methyl ethyl ketone, methanol, ethanol, butanol, and ethyl acetate;

    - hydrocarbon solvents such as hexanes, Stoddard, benzene, toluene, xylenes, and paint thinner.

- Used of unused petroleum products, including motor oils, hydraulic fluids, cutting lubricants, and fortified weed oils.

- Pickling liquor.

- Acids such as hydrochloric, hydrofluoric, nitric, phosphoric, and sulfuric, in concentrations exceeding 15 per cent.

- Alkalis, including hydroxides and carbonates of sodium, potassium, and calcium and acetylene sludges.

- Empty containers of iron or steel used for pesticides or other hazardous chemicals.

## TABLE H-1

## MAXIMUM CONCENTRATION OF CONTAMINANTS FOR CHARACTERISTIC OF EP TOXICITY

| EPA Hazardous Waste Number | Contaminant | Maximum Concentration (mg/L) |
|---|---|---|
| D004 | Arsenic | 5.0 |
| D005 | Barium | 100.0 |
| D006 | Cadmium | 1.0 |
| D007 | Chromium VI | 5.0 |
| D008 | Lead | 3.0 |
| D009 | Mercury | 0.2 |
| D010 | Selenium | 1.0 |
| D011 | Silver | 5.0 |
| D012 | Endrim (1,2,3,4,10,10-hexachloro-1,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo,endo-5,8-dimethano naphthalene | 0.02 |
| D013 | Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer | 0.4 |
| D014 | Methoxychlor (1,1,1-Trichloro-2,2-bis [p-methoxphenyl] ethane). | 0.3 |
| D015 | Toxaphene ($C_{10}H_{10}Cl_3$), Technical chlorinated camphene, 67-69 per cent chlorine) | 0.05 |
| D016 | 2,4-D (2,4-Dichlorophenoxyacetic acid) | 10.0 |
| D017 | 2,4,5-TP Silvex (2,4,5-Trichlorophenoxy-propioric acid) | 1.0 |
|  | Aldrin | 0.03 |
|  | Chlordane | 0.1 |
|  | DDT | 0.01 |
|  | Heptachlor | 0.01 |
|  | Mirex | 0.01 |
|  | Polycholorinated biphenyl (PCB) | 0.01 |

For a waste to exhibit low leachability, the following conditions must be met:

1. Acutely toxic constituents are not present in the extract at concentrations expressed in milligrams per litre (mg/L) greater than 0.00056 times the rat oral $LD_{50}$ expressed in milligrams per kilogram. This shall apply to toxic constituent having an oral rat $LD_{50}$ less than or equal to 500 mg/kg according to the Registry of Toxic Effects of Chemical Substances, 1980 Edition, prepared for the National Institute for Occupational Safety and Health.

2. Positive human carcinogens are not present in the extract at concentrations greater than 0.01 mg/L. The constituents for which this applies are listed below:

   - Asbestos
   - Auramine
   - Benzene
   - Benzidine
   - N, N-bis (2-chloroethyl) 2-naphthylamine
   - Bis (chloromethyl) ether
   - Chloromethyl methyl ether
   - Diethylstilbesterol
   - Melphalan
   - 2-Naphthylamine
   - Vinyl chloride

# APPENDIX I
# INCOMPATIBLE WASTE GROUPS

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# INCOMPATIBLE WASTE GROUPS

(Source: Hatayama, H.K. et al., A Method for Determining the Compatibility of Hazardous Wastes, EPA-600/2-80-076).

The following is a summarized version of a system developed by the California Department of Health Services for assessing the compatibility of hazardous wastes. The system groups the spectrum of hazardous wastes into 41 reactivity group classifications as presented on Figure I-1.

The first column of the chart lists the reactivity groups of Reactivity Group Numbers (RGN). The first 34 RGN which are based on chemical classes or molecular functional groups are listed consecutively from 1 to 34. The last RGN which are based on general chemical reactivities are listed consecutively from 101 to 107. The second column lists the corresponding reactivity group names. The first 34 group names are each followed by a number of reaction squares equal to their respective RGN. In other words, RGN 1 is followed by 1 square, RGN 2 by 2 squares, etc. The group names designated by RGN 101 to 107 are followed by 34, 36, 37, 38, 39, 40 and 41 squares, respectively. The squares form rows as well as columns of squares on the chart. A terminal square of a row represents a binary combination of one reactive group with itself and is labelled with its RGN. The terminal squares serve as headings for the columns of squares and as a whole appear as a diagonal row of squares on the chart. An additional bottom row of squares is correspondingly labelled as the diagonal row of squares. The RGN on the first column of the chart and those on the diagonal and bottom rows of squares provide the reference coordinates for locating the potential hazardous reaction consequences of any binary combinations of the wastes reactivity groups.

The rest of the squares on the chart are either blank or filled in with Reaction Codes (RC). When a square is blank, the wastes in the binary combination represented by that square are compatible. Conversely, any RC on the squares indicate potential incompatible reactions that can result from the combination of the wastes reactivity groups represented by the individual squares. The predicted reactions are based on the combinations of the most reactive chemicals in the respective reactivity groups. Where waste combinations are believed to be incompatible but not sufficient supporting data have been found in the literature, incompatible reactions are also noted and marked on the chart with RC or "U". The RC are identified in the legend on the upper right-hand corner of Figure I-1.

## Procedures for Using the Chart

Step 1: For the binary combination of any reactivity groups, first find the Reactivity Group Number (RGN) of the first group on the first column of the chart.

Step 2: Find the RGN of the second group from the bottom squares of RGN.

Step 3: Find the intersecting reaction square for the two RGN.

Step 4: Note the Reaction Code(s) (RC) in the square.

Step 5: Refer to the legend on the chart for the explanation of the RC.

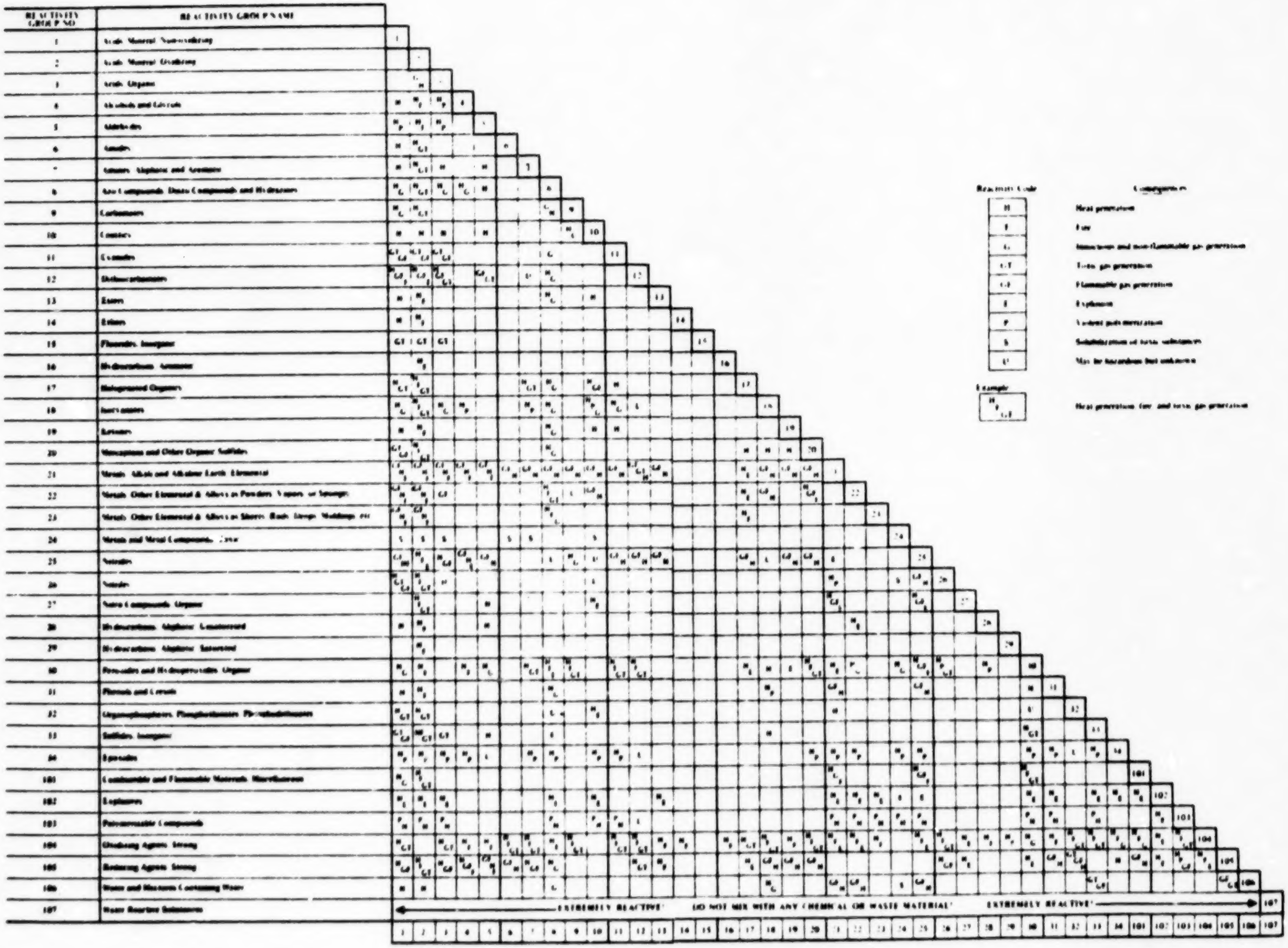
Step 6: When no RC is found on the reaction square, the two groups of wastes are compatible. When any RC is noted on the square, the wastes are incompatible when mixed or allowed to come in contact with one another.

## Explanation of the Multiple Reaction Codes

For many binary combinations, multiple Reaction Codes (RC) are used to denote the reaction consequences. The order in which these letter codes appear in the squares corresponds to the order in which the consequences can occur. For example, in RC ($H_{FE}$), the first letter denotes the initial or primary hazardous consequence of a binary reaction which in this case is HEAT generation. The second and third letters denote the resulting secondary consequences of the production of FIRE and EXPLOSION from the heat generated by the primary reaction. In some cases the third letter code refers to a resulting tertiary consequence such as the evolution of a toxic gas from a fire cased by excessive HEAT generation e.g. ($H_{FGT}$). Where the codes $GT_{GF}$ appear, the GASES evolved are TOXIC and FLAMMABLE such as hydrogen sulfide, hydrogen cyanide, or carbon disulfide. The relative positions of the letter codes to one another in this case bear no significance. The codes can also be written as $GF_{GT}$.

## Limitations of the Chart

The potential reaction consequences predicted by the chart are based on pure chemical reactions only at ambient temperature and pressure. Concentration, synergistic, and antagonistic effects have been assumed not to influence the reactions. The reactions have not as yet been validated on actual wastes containing the chemicals.



| REACTIVITY GROUP NO. | REACTIVITY GROUP NAME |
|---|---|
| 1 | Acids, Mineral, Non-oxidizing |
| 2 | Acids, Mineral, Oxidizing |
| 3 | Acids, Organic |
| 4 | Alcohols and Glycols |
| 5 | Aldehydes |
| 6 | Amides |
| 7 | Amines, Aliphatic and Aromatic |
| 8 | Azo Compounds, Diazo Compounds and Hydrazines |
| 9 | Carbamates |
| 10 | Caustics |
| 11 | Cyanides |
| 12 | Dithiocarbamates |
| 13 | Esters |
| 14 | Ethers |
| 15 | Fluorides, Inorganic |
| 16 | Hydrocarbons, Aromatic |
| 17 | Halogenated Organics |
| 18 | Isocyanates |
| 19 | Ketones |
| 20 | Mercaptans and Other Organic Sulfides |
| 21 | Metals, Alkali and Alkaline Earth, Elemental |
| 22 | Metals, Other Elemental & Alloys as Powders, Vapors, or Sponges |
| 23 | Metals, Other Elemental & Alloys as Sheets, Rods, Drops, Moldings, etc. |
| 24 | Metals and Metal Compounds, Toxic |
| 25 | Nitrides |
| 26 | Nitriles |
| 27 | Nitro Compounds, Organic |
| 28 | Hydrocarbons, Aliphatic, Unsaturated |
| 29 | Hydrocarbons, Aliphatic, Saturated |
| 30 | Peroxides and Hydroperoxides, Organic |
| 31 | Phenols and Cresols |
| 32 | Organophosphates, Phosphothioates, Phosphodithioates |
| 33 | Sulfides, Inorganic |
| 34 | Epoxides |
| 101 | Combustible and Flammable Materials, Miscellaneous |
| 102 | Explosives |
| 103 | Polymerizable Compounds |
| 104 | Oxidizing Agents, Strong |
| 105 | Reducing Agents, Strong |
| 106 | Water and Mixtures Containing Water |
| 107 | Water Reactive Substances |

← EXTREMELY REACTIVE! DO NOT MIX WITH ANY CHEMICAL OR WASTE MATERIAL! EXTREMELY REACTIVE! →

| Reactivity Code | Consequences |
|---|---|
| H | Heat generation |
| F | Fire |
| G | Innocuous and non-flammable gas generation |
| GT | Toxic gas generation |
| GF | Flammable gas generation |
| E | Explosion |
| P | Violent polymerization |
| S | Solubilization of toxic substances |
| U | May be hazardous but unknown |

Example

| $H_{F_{GT}}$ | Heat generation, fire, and toxic gas generation |
|---|---|

FIGURE I-1
HAZARDOUS WASTE COMPATIBILITY CHART

# APPENDIX J
# SOLIDIFICATION PROCESSES

# APPENDIX J
# SOLIDIFICATION PROCESSES

(Source: Environment Council of Alberta. Public hearings on Hazardous Waste Management in Alberta, December 1980.)

Solidification processes are designed to decrease the leachability of landfilled material by decreasing the permeability of the waste to liquids. There are two major types: fixation where the waste is chemically or physically bound to the solidifying material and encapsulation where the waste is unreacted but encased in a water insoluble material (for example, plastic or glass). The present solidification processes are:

Fixation

- Cement-based
- Lime-based
- Thermoplastic-based
- Organic-polymer-based

Encapsulation

- Encapsulation

## Cement-Based Processes

Wet organic wastes (preferably sludges) can be mixed with cement and other additives such as fly ash to form a type of concrete. Usually the mix is landfilled before solidification takes place. The system is suitable for sludges containing heavy metals since the cement mixture has a high pH and keeps the salts in the form of insoluble hydroxides and carbonates. Organic materials produce problems with setting and accordingly the amount of allowable organics in the waste is limited.

## Lime-Based Processes

When lime is mixed with siliceous material and water, a hard material called pozzolanic concrete is formed. This was the concrete used by the ancient Romans and is still intact today. For waste disposal, inorganic sludge and fly ash is mixed with lime and siliceous material to form the pozzolanic concrete.

Setting times are longer than for cement-based solidification and after placing the unset material in a landfill, compaction may be required. When organic materials are present, setting and curing problems exist as for the cement-based systems. In this case, the presence of organic material results in lower shear strength and increased permeability.

Chem Nuclear Systems (brief 70) and Stablex Corporation (brief 155) both appear to be describing a lime-based solidification method.

## Thermoplastic-Based Process

Dried waste can be mixed with hot paraffin, hot polyethylene or hot bitumen. When the mixture cools it solidifies. The solidification is usually carried out in a container or a further thermoplastic coating is applied. The containers or coated materials are then ready for landfilling. Here again the object is to reduce leaching. Materials unsuitable for thermoplastic based solidification are those which dissolve the binder or contain high concentrations of strong oxidizing salts. The processes are a sort of mini-encapsulation with the thermoplastic material coating each waste particle.

Because the material is water insoluble, the end product resists leaching by most aqueous solutions to an even greater extent than cement or lime-based systems.

## Organic Polymer Processes

Certain wastes can be mixed with monomer and then polymerized with catalyst to form polymer which is either containerized prior to disposal or allowed to set in the landfill. The polymer typically does not chemically fix the waste but merely binds it. However, Walker Brothers (brief 139) claim the Soliroc process "reacts with and does not merely encapsulate the heavy metals".

A common polymer technique was based on urea-formaldehyde polymerization. In the past there was a problem with the weeping of contained water; however, recent refinements in the process appear to have overcome the problem.

Browning Ferris Industries (brief 159) mentioned a solidification process which could be an organic polymer process but is more likely a cement or lime-based process.

All types of solidification appear to be available in Canada. More than one of these processes could be needed in order to handle both inorganic and organic wastes. In the case of organic toxic wastes, however, solidification would likely be a second choise to incineration.

Solidification plants, of course, should be located near a landfill, particularly when landfilling of unset material is desired. The landfill should be of the secure variety since long-term effects of weathering, and so on, cannot be assessed without long-term research. Data obtained to date, however, indicates that very significant reduction in leachate concentration takes place over the short term. The conclusions of a recent study (Johnson & Lancione in EPA 1980b), states taht "Commercially available processes offer a wide range of effectiveness in reducing the leaching of arsenic from waste discussed here. ...Some processes reduced leaching rates by more than four order of magnitude relative to raw wastes and some less effective processes." The effectiveness was site-specific, indicating that proper landfill siting is essential. The study pointed out that the choice of process is crucial to the success of the fixation.

## Encapsulation

In this process, toxic materials are placed in a container, then coated with material such as butyl rubber or high density polyethylene, and so on. The process is expensive, and will prove ineffective if the container is ruptured, but may be suitable for small volumes of highly toxic materials. Normally one would expect some form of detoxification to take place prior to encapsulation; however, some substances cannot be further reduced in toxicity. Encapsulation is sometimes used in accident clean-up procedures.

Costs for solidification processes range from $5 to $50 a tonne depending on the method used and characteristics of the waste. They are often not subject to economies of scale since capital equipment and facilities are minimal.

# APPENDIX K
# EP TOXICITY TEST PROCEDURE

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The EP Toxicity Test referred to in Appendix F is detailed as follows:

## A. Extraction Procedure (EP)

1. A representative sample of the waste to be tested (minimum size 100 grams) should be obtained using the methods capable of yielding a representative sample within the meaning of Part 260. (For detailed guidance on conducting the various aspects of the EP see "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods, "SW-846 - U.S. Environmental Protection Agency Office of Solid Waste, Washington, D.C. 20460.[1])

2. The sample should be separated into its component liquid and solid phases using the method described in "Separation Procedure" below. If the solid residue[2] obtained using this method totals less than 0.5 per cent of the original weight of the waste, the residue can be discarded and the operator should treat the liquid phase as the extract and proceed immediately to Step 8.

3. The solid material obtained from the Separation Procedure should be evaluated for its particle size. If the solid material has a surface area per gram of material equal to, or greater than, 3.1 $cm^2$ or passes through a

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[1] Copies may be obtained from Solid Waste Information, U.S. Environmental Protection Agency, 26 W. St. Clair Street, Cincinnati, Ohio 45268.

[2] The percent solids is determined by drying the filter pad at 80°C until it reaches constant weight and then calculating the percent solids using the following equation.

$$\frac{(\text{weight of pad + solid}) - (\text{tare weight of pad})}{\text{initial weight of sample}} \times 100 = \%\ \text{solids}$$

9.5 mm (0.375 inch) standard sieve, the operator should proceed to Step 4. If the surface area is smaller or the particle size larger than specified above, the solid material should be prepared for extraction by crushing, cutting or grinding the material so that it passes through a 9.5 mm (0.375 inch) sieve or, if the material is in a single piece, by subjecting the material to the "Structural Integrity Procedure" described below.

4. The solid material obtained in Step 3 should be weighed and placed in an extractor with 16 times its weight of deionized water. Do not allow the material to dry prior to weighing. For purposes of this test, an acceptable extractor is one which will impact sufficient agitation to the mixture to not only prevent stratification of the sample and extraction fluid but also insure that all sample surfaces are continuously brought into contact with well mixed extraction fluid.

5. After the solid material and deionized water are placed in the extractor, the operator should begin agitation and measure the pH of the solution in the extractor. If the pH is greater than 5.0, the pH of the solution should be decreased to 5.0 ± 0.2 by addition of 0.5N acetic acid. If the pH is equal to or less than 5.0, no acetic acid should be added. The pH of the solution should be monitored, as described below, during the course of the extraction and if the pH rises above 5.2, 0.5N acetic acid should be added to bring the pH down to 5.0 ± 0.2. However, in no event shall the aggregate amount of acid added to the solution exceed 4 mL of acid per gram of solid. The mixture should be agitated for 24 hours and maintained at 20°-40°C (68°-104°F) during this time. It is recommended that the operator monitor

and adjust the pH during the course of the extraction with a device such as the Type 45-A pH Controller manufactured by Chemtrix, Inc., Hillsboro, Oregon 97123 or its equivalent, in conjunction with a metering pump and reservoir of 0.5N acetic acid. If such a system is not available, the following manual procedure shall be employed:

a) A pH meter should be calibrated in accordance with the manufacturer's specifications.

b) The pH of the solution should be checked and, if necessary, 0.5N acetic acid should be manually added to the extractor until the pH reaches 5.0 ± 0.2. The pH of the solution should be adjusted at 15, 30 and 60 minute intervals, moving to the next longer interval if the pH does not have to be adjusted more than 0.5N pH units.

c) The adjustment procedure should be continued for at least six hours.

d) If at the end of the 24-hour extraction period, the pH of the solution is not below 5.2 and the maximum amount of acid (4 mL per gram of solids) has not been added, the pH should be adjusted to 5.0 ± 0.2 and the extraction continued for an additional four hours, during which the pH should be adjusted at one hour intervals.

6. At the end of the 24-hour extraction period, deionized water should be added to the extractor in an amount determined by the following equation:

   $V = (20)(W)-16\ (W)-A$
   V = mL deionized water to be added
   W = weight in grams of solid charged to extractor
   A = mL of 0.5N acetic acid added during extraction

7. The material in the extractor should be separated into its component liquid and solid phases as described under "Separation Procedure".

8. The liquids resulting from Steps 2 and 7 should be combined. This combined liquid (or the waste itself if it has less than 1/2 per cent solids, as noted in Step 2) is the extract and should be analyzed for the presence of any of the contaminants specified in Table F-I in Appendix F using the Analytical Procedures designated below.

**Separation Procedure**

Equipment: A filter holder, designed for filtration media having a nominal pore size of 0.45 $\mu$ and capable of applying a 5.3 kg/cm$^2$ (75 psi) hydrostatic pressure to the solution being filtered shall be used. For mixtures containing non-absorptive solids, where separation can be affected without imposing a 5.3 kg/cm$^2$ pressure differential, vacuum filters employing a 0.45 $\mu$ filter media can be used. (For futher guidance on filtration equipment for procedures see "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods").

**Procedure**[3]

1. Following manufacturer's directions, the filter unit should be assembled with a filter bed consisting of a 0.45 µ filter membrane. For difficult or slow to filter mixtures a prefilter bed consisting of the following prefilters in increasing pore size (0.65 µ membrane, fine glass fiber prefilter, and coarse glass fiber prefilter) can be used.

2. The waste should be poured into the filtration unit.

3. The reservoir should be slowly pressurized until liquid begins to flow from the filtrate outlet at which point the pressure in the filter should be immediately lowered to 10 to 15 psig (170 to 205 kpa). Filtration should be continued until liquid flow ceases.

4. The pressure should be increased stepwise in 10 psi (70 kpa) increments to 75 psig (620 kpa) and filtration continued until flow ceases or the pressurizing gas begins to exit from the filtrate outlet.

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[3] This procedure is intended to result in separation of the "free" liquid portion of the waste from any solid matter having a particle size >0.45 µ. If the sample will not filter, various other separation techniques can be used to aid in the filtration. As described above, pressure filtration is employed to speed up the filtration process. This does not alter the nature of the separation. If liquid does not separate during filtration, the waste can be centrifuged. If separation occurs during centrifugation the liquid portion is filtered through the 0.45 µ filter prior to becoming mixed with the liquid portion of the waste obtained from the initial filtration. Any material that will not pass through the filter after centrifugation is considered a solid and is extracted.

5. The filter unit should be depressurized, the solid material removed and weighed and then transferred to the extraction apparatus, or, in the case of final filtration prior to analysis, discarded. Do not allow the material retained on the filter pad to dry prior to weighing.

6. The liquid phase should be stored at 4°C for subsequent use in Step 8.

## B. Structural Integrity Procedure

Equipment: A Structural Integrity Tester having a 3.18 cm (1.25 inch) diameter hammer weighing 0.33 kg (0.73 lbs.) and having a freefall of 15.24 cm (6 inches) shall be used. This device is available from Associated Design and Manufacturing Company, Alexandria, Virginia 22314, as Part No. 125, or it may be fabricated to meet required specifications.

### Procedure

1. The sample holder should be filled with the material to be tested. If the sample of waste is a large monolithic block, a portion should be cut from the block having the dimensions of a 3.3 cm (1.3 inch) diameter x 7.1 cm (2.8 inch) cylinder. For a fixated waste, samples may be cast in the form of a 3.3 cm (1.3 inch) diameter x 7.1 cm (2.8 inch) cylinder for purposes of conducting this test. In such cses, the waste may be allowed to cure for 30 days prior to further testing.

2. The sample holder should be placed into the Structural Integrity Tester, then the hammer should be raised to its maximum height and dropped. This should be repeated 15 times.

3. The material should be removed from the sample holder, weighed, and transferred to the extraction apparatus for extraction.

**Analytical Procedures for Analyzing Extract Contaminants**

The test methods for analyzing the extract are as follows:

1. For arsenic, barium, cadmium, chromium, lead, mercury, selenium or silver. "Methods for Analysis of Water and Wastes," Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45266 (EPA-600/4-79-020, March 1979).

2. For Endrin; Lindane; Methoxychlor, Toxaphene; 2,4-D; 2,4,5-TP Silver: in "Methods for Benzidine, Chlorinated Organic Compounds, Pentachlorophenol and Pesticides in Water and Wastewater," September 1978, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 42568 as standardized in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods."

   For all analyses, the method of standard addition shall be used for the quantification of species concentration. This method is described in "Test Methods for the Evaluation of Solid Waste." (It is also described in "Methods for Analysis of Water and Wastes").

# APPENDIX L
# SYNTHETIC MEMBRANES USED AS LANDFILL LINERS

## APPENDIX L
## SYNTHETIC MEMBRANES USED AS LANDFILL LINERS

(Source: Haxo, H.E., et al, Lining of Waste Impoundment and Disposal Facilities, U.S. EPA, September 1980.)

### Butyl Rubber

Liners of butyl rubber were among the first synthetic liners to be used for potable water impoundment and have been in this type of service for about 30 years (Smith, 1980).

Butyl rubber is a copolymer of isobutylene (97 per cent) with small amounts of isoprene introduced to furnish sites for vulcanization (Morton, 1973, pp. 249-259). The important properties of butyl rubber to its use as a liner are:

- liner gas and water vapor permeability;
- thermal stability;
- ozone and weathering resistance;
- chemical and moisture resistance;
- resistance to animal and vegetable oils and fats.

It is generally compounded with fillers and some oil and vulcanized with sulfur. Butyl vulcanizates are highly swollen by hydrocarbon solvents and petroleum oils, but are only slightly affected by oxygenated solvents and other polar liquids. Butyl also has a high resistance to mineral acids. After 13 weeks of immersion in 70 per cent sulfuric acid, a butyl compound showed little loss in tensile strength of elongation (Morton, 1973, pp. 249-259). Butyl rubber has a high tolerance for extremes in temperature and retains its flexibility throughout its service life. It has good tensile strength and desirable elongation qualities.

Butyl rubber liners are manufactured in both reinforced and unreinforced versions. They are difficult to seam and to repair. They require special room temperature vulcanizing adhesives (Kumar and Jedlicka; Lee, 1974).

## Chlorinated Polyethylene

Chlorinated polyethylene (CPE) is produced by a chemical reaction between chlorine and high-density polyethylene. Presently available polymers contain 25 to 45 per cent chlorine and 0 to 25 per cent crystallinity. CPE is compounded and used in thermoplastic and cross-linked compositions.

Since CPE is a completely saturated polymer (no double bonds) it is not susceptible to ozone attack and weathers well. The polymer also has good tensile and elongation strength. Chlorinated polyethylene is characterized by resistance to deterioration by many corrosive and toxic chemicals. Because they contain little or no plasticizer, CPE liners have good resistance to growth of mold, mildew, fungus, and bacteria. Membranes of CPE can also be formualted to withstand intermittent contact with aliphatic hydrocarbons and oils. CPE will swell in the presence of high concentrations of aromatic hydrocarons and oils but regains some of its original properties when removed from that environment. Continuous exposure to aromatics will shorten the service life of the liner. In most cases CPE liners are not recommended for containment of aromatic liquids (Dow, 1977).

CPE can be compounded with other polymers, making it a feasible base material for a broad spectrum of liners. CPE can be alloyed with PVC, PE and numerous synthetic rubbers. Nevertheless, at least half the polymer content of CPE liners is CPE resin. CPE is widely used to improve the stress crack resistance and softness of ethylene polymers and to improve the cold crack resistance of flexible polyvinyl chloride. CPE membranes are available in varied thickness in unreinforced of fabric reinforced versions (Bureau of Reclamation, 1963, p.23). Membranes of CPE are generally unvulcanized and thus can be seamed by bodied-solvent adhesives, solvent welding or dielectric heat sealing (Steward, 1978).

## Chlorosulfonated Polyethylene (CSPE)

Chlorosulfonated polyethylene is a family of polymers prepared by reacting polyethylene in solution with chlorine and with sulfur dioxide. Presently available polymers contain from 25 to 43 per cent chlorine and from 1.0 to 1.4 per cent sulfur. They can be used in both thermoplastic (uncross-linked) and in vulcanized (cross-linked) compositions. Uncured CSPE is more thermoplastic than other commonly used elastomers. It is generally tougher at room temperature, but softens more rapidly as temperatures are increased (Morton, 1973, pp.337-338).

Chlorosulfonated polyethylene (CSPE) is characterized by ozone resistance, light stability, heat resistance, good weatherability, and resistance to deterioration by corrosive chemicals, e.g. acid and alkalies. It has good resistance to growth in both vulcanized and thermoplastic forms, but primarily in the latter. Usually, they are reinforced with a polyester or nylon scrim and generally contain at least 45 per cent of CSPE polymer. The fabric reinforcement gives needed tear strength to the sheeting for use on slopes, and reduces the distortion resulting from shrinkage when placed on the base and when exposed to the heat of the sun.

CSPE can be seamed by heat sealing, dielectric heat sealing, solvent welding, or by using "bodied" solvent adhesive. Membranes of this polymer do not crack or fail at extremes of temperatures or from weathering. Disadvantages of CPSE membranes are low tensile strength, a tendency to shrink from exposure to sunlight (Clar and Moyer, 1974, p. 20), and relatively poor resistance to oils. Also, some CSPE tends to harden on aging, due to cross-linking by moisture, ultraviolet radiation, and heat.

Membranes of CSPE are also available in colours other than black, without appreciable loss of other desirable characteristics (DuPont, 1979).

## Elasticized Polyolefins

Elasticized polyolefin is a blend of rubbery and crystalline polyolefins. This polymeric material was introduced in 1975 as a black unvulcanized, thermoplastic liner, which readily and easily heat sealed with a specially designed heat welder in the field or at the factory. It has a low density (0.92) and is highly resistant to weathering, alkalis, and acids (Haxo and White, 1977). This membrane is unsupported and is manufactured by blow extrusion and supplied in sheets 20 mil thick, 20 feet wide, and up to 200 feet long (DuPont, 1979) which are shipped to site for assembly in the field.

Some difficulties have been encountered with elasticized polyolefin in low temperature and high winds, in oily environments, and in adhesion to structures.

## Epiclorohydrin Rubbers (CO and ECO)

Included in this classification are two epichlorohydrin-based elastomers which are saturated, high molecular weight, aliphatic polyethers with cloromethyl side chains. The two types include a homopolymer and a copolymer of epichlorohydrin and ethylene oxide. These materials are vulcanized with a variety of reagents that react difunctionally with the chloromethyl group, including diamines, urea, thioreas, 2-mercaptoimidazoline, and ammonium salts.

Epichlorohydrin elastomer vulcanizates exhibit the following characteristics:

- resistance to hydrocarbon solvents, fuels and oils;
- ozone and weathering resistance;
- low rate of gas/vapour permeability;
- thermal stability;
- good tensile and tear strength.

Epichlorohydrin rubber has a high tolerance for temperature extremes and retains its flexibility at extreme temperatures throughout its service life. The homopolymer has a performance range of 0 to 325°F. The copolymer shows improved low temperature flexibility and is recommended for service from -40 to 300°F.

Epichlorohydrin elastomers can be seamed with room temperature vulcanizing adhesives.

## Ethylene Propylene Rubber (EPDM)

Ethylene propylene rubbers are a family of terpolymers of ethylene, propylene, and a minor amount of nonconjucated diene hydrocarbon. The diene supplies double bonds to the saturated polymer chain to be chemically active sites for vulcanization, usually with sulfur. These rubbers vary in ethylene: propylene ratio, in the type and amount of the third monomer, and in molecular weight. Although EPDM liners are generally based on vulcanized compounds, thermoplastic EPDM liners are also available. Both versions are manufactured as fabric reinforced and unsupported sheeting.

Liners based on vulcanized EPDM compounds have excellent resistance to weather and ultraviolet exposure and, when compounded properly, resist abrasion and tear. Because of its excellent ozone resistance, minor amounts of EPDM are sometimes added to butyl to improve the weather resistance of the latter. EPDM liners tolerate extremes of temperature, and maintain their flexibility at low temperatures. They are resistant to dilute concentrations (10 per cent by weight) of acids, alkalis, silicates, phosphates, and brine, but are not recommended for petroleum solvents (hydrocarbons) or for aromatic or halogenated solvents.

Vulcanized EPDM membranes require the use of special cements and careful application to assure satisfactory field seaming. The proposed seam construction should be tested in the use environment to assure serviceability. Thermoplastic EPDM liners are seamed by thermal methods.

## Neoprene

Neoprene is the generaic name of synthetic rubbers based upon chloroprene. These rubbers are vulcanizable, usually with metal oxides, but also with sulfur. They closely parallel natural rubber in mechanical properties, e.g. flexibility and strength. However, neoprene is superior to natural rubber in its resistance to oils, weathering, ozone and ultraviolet radiation. Neoprene is resistant to puncture, abrasion, and mechanical damage. Neoprene membranes have been used primarily for the containment of waste water and other liquids containing traces of hydrocarbons. They also give satisfactory service with certain combinations of oils and acids for which other materials do not provide long-term (Kumar and Jedlicka, 1973; Lee, 1974).

Neoprene sheeting for liners is vulcanized, thus vulcanizing cements and adhesives must be used for seaming.

## Polyethylene

Polyethylene is a thermoplastic polymer based upon ethylene. It is made in two major types: (1) low density polyethylene, and (2) high density polyethylene. The properties of a polyethylene are largely dependent upon its crystalinity and density. High density polyethylene polymers exhibit superior resistance to oils, solvents, and permeation by water vapour and gases. Unprotected clear polyethylene degrades readily on outdoor exposure, but the addition of 2 to 3 per cent carbon black can produce improved ultraviolet light protection. Polyethylenes, for the most part, are free of additives such as plasticizers and fillers.

Both types of polyethylene have been used as liners. Membranes of low density polyethylene have been used unsupported for 15 to 20 years (Hickey, 1969) in lining canals and ponds. Recently, high density polyethylene in heavy sheeting has been introduced. The low density polyethylene (LDPE) available in thin sheeting tends to be difficult to handle and to field seam. Also, it is punctured easily under impact such as when rocks are dropped on the lining; however, it has good service puncture resistance as a buried membrane lining. Linings of high density polyethylene (HDPE) recently introduced are available in thick sheets up to 125 mil; special seaming equipment has been developed for making seams both in the factory and in the field. This type of liner is very stiff compared to most of the other membranes described.

## Polyvinyl Chloride

Polyvinyl chloride is produced by any of several polymerization processes from vinyl chloride monomer (VCM). It is a versatile thermoplastic polymer which is compounded with plasticizers and other modifiers to produce a wide range of physical properties.

PVC liners are produced in roll form in various widths and thicknesses. Most liners are used as unsupported sheeting, but fabric reinforcement can be incorporated. PVC compounds contain 25 to 35 per cent of one or more plasticizers to make the sheeting flexible and rubber-like. They also contain 1 to 5 per cent of a chemical stabilizer and various amounts of other additives. The PVC compound should not contain any water soluble ingredients. There is a wide choice of plasticizers that can be used in PVC sheeting, depending upon the application and service conditions under which the PVC compound will be used. Plasticizer loss during service is a source of PVC degradation. There are three basic mechanisms for plasticizer loss: volatilization, extraction, and microbiological attack. The use of the proper plasticizers and an effective biocide can virtually eliminate microbiological attack and minimize volatility and extraction. The PVC polymer, itself, is not affected by these conditions. It is affected, however, by ultraviolet exposure.

The principal reason for loss of plasticizer is by volatilization in the heat of the sun rather than solution in the waste fluid. Carbon black prevents ultraviolet attack but does cause the absorption of solar energy raising the temperature to a high level to cause vaporization of plasticizer. A soil or other suitable cover material used to bury the liner protects it from ultraviolet exposure and reduces the rate of plasticizer loss. PVC sheeting is not recommended for exposure to weathering and ultraviolet light conditions during its service life.

Plasticized PVC sheeting has good tensile, elongation, and puncture and abrasion resistance properties. It is readily seamed by solvent welding, adhesives, and heat and dielectric methods.

PVC membranes are the most widely used for all polymeric membranes for waste impoundments. They show good chemical resistance to many inorganic chemicals (Chan et al 1978, p.19); however, they are attacked by many organic chemicals, particularyly hydrocarbons, solvents, and oils. Special compounds of PVC are available, designated as Oil-Resistant PVC (PVCOR), that possesses high resistance to oil attack. These "oil resistant" grades of sheeting must be made with "specialty" plasticizers; the PVC polymer is inherently resistant to the effects of oils.

Polymers such as nitrile rubber, CPE and EVA may be used to replace the liquid plasticizers so that the PVC liner is not affected by the waste fluid.

## Thermoplastic Elastomers (TPE)

Thermoplastic elastomers are a relatively new class of rubbery materials (Walker, 1979). They include a wide variety of polymeric compositions from highly polar materials, such as the polymer elastomers, to the non-polar materials, such as ethylene-propylene block polymers. These polymers are thermoplastic and non-vulcanized. They are processed and shaped at relatively high temperatures at which they are plastic; when they are cooled to normal ambient temperatures, they behave like vulcanized rubbers. Products made of these polymers have a limited upper temperature service range, which, however, is substantially above the temperatures encountered in waste disposal sites.

Of particular potential interest for use in liners are the polyolefin thermoplastic elastomers such as thermoplastic EPDM, which are probably related to the elasticized polyolefins, and nitrile rubber/PVC blends for oil resistant liners. Such liner materials are now under development and test.

Nitrile/PVC thermoplastic elastomer blends have excellent oil, fuel, and water resistance with high tensile strength and excellent resistance to ozone and weathering. Blends tend to stiffen at low temperatures but remain serviceable.

As with liners of other thermoplastic polymers, liners of thermoplastic elastomers can be heat sealed to make seams and should be easy to repair; however, their durability in various chemical environments remains to be tested.

# APPENDIX M

# TRANSPORTATION OF HAZARDOUS WASTE AND FEDERAL MANIFEST (INTERPROVINCIAL/INTERNATIONAL) SYSTEM

# Transportation of Hazardous Waste and Federal Manifest (Interprovincial/International) System

Hazardous wastes are crossing provincial boundaries within Canada and are moving across Canada's international borders. At present there are no methods to control these movements and to ensure that these wastes receive proper treatment, storage and/or disposal. Also, there is no indication as to the type or quantity of these wastes.

Measures are therefore being taken to bring these wastes under control. Hazardous wastes, in transit, will have to comply with all of the requirements of the proposed Transportation of Dangerous Goods Act which is administered by the Department of Transport. This Act will require all dangerous goods, including hazardous wastes, to be properly identified (i.e. waste type and hazard class) and packaged (adequate containers). The control document to be used for transportation of dangerous goods is the way-bill or declaration.

A waste manifest system, on the other hand, must achieve two things: Firstly, it must ensure that all of the requirements of the transportation way-bill (declaration) are met - these relate mainly to the transportation stage itself; secondly, and of equal importance for dangerous wastes, is the requirement that the load must be delivered to a provincially authorized destination. This second condition goes beyond the normal transportation requirement.

It is understood in the above argument that, for waste shipments, the manifest document will replace the way-bill (declaration) by accommodating all of the way-bill requirements, thus avoiding duplication of paperwork.

The Province of Ontario, has thus far attempted to implement an intraprovincial manifest. The Ontario system has been operational for several years, has been gradually refined and is, at present, undergoing further revision.

The purpose of the proposed federal manifest (copies of the draft forms are attached), is to ensure that hazardous wastes crossing interprovincial and international boundaries and coming into Canada are delivered to provincially authorized storage, treatment and/or disposal facilities. For international shipments, federal authorization will be required in addition to the provincial authorization.

It is proposed in this federal system, to exercise control of transboundary waste movement by means of a "matching manifest". A "matching manifest" is one where the generator of hazardous waste prepares a manifest, retains two copies and forwards the remaining copies with the hazardous waste shipment to a hazardous waste management facility where the maniest is completed by the receiver on its arrival. Both the generator and receiver of hazardous waste forward copies of the manifest to the appropriate regulatory authority of the province where the receiver is located where the copies are matched to ensure the arrival of the correct type and quantity of waste. The transporter must also be prepared to produce the manifest for inspection should he be stopped in transit. In this way the waste movement is known and can be controlled on a day-to-day basis. In any event, before a generator outside of the province or country can ship hazardous waste into the receiving province, he is required to prenotify the regulatory authority of the province of receipt and receive authorization. For international shipments, federal authorization will be required. This will mean that interprovincial and international shipments which either do not confirm to our requirements or are being sent to unacceptable destinations will be screened out in advance. It will also assist in the policing of interprovincial and international waste movements.

Hazardous waste for the proposed federal hazardous waste manifest will be specified in accordance with the definition, listings and criteria that are being developed by a joint Federal/Provincial/Industry Working Group.

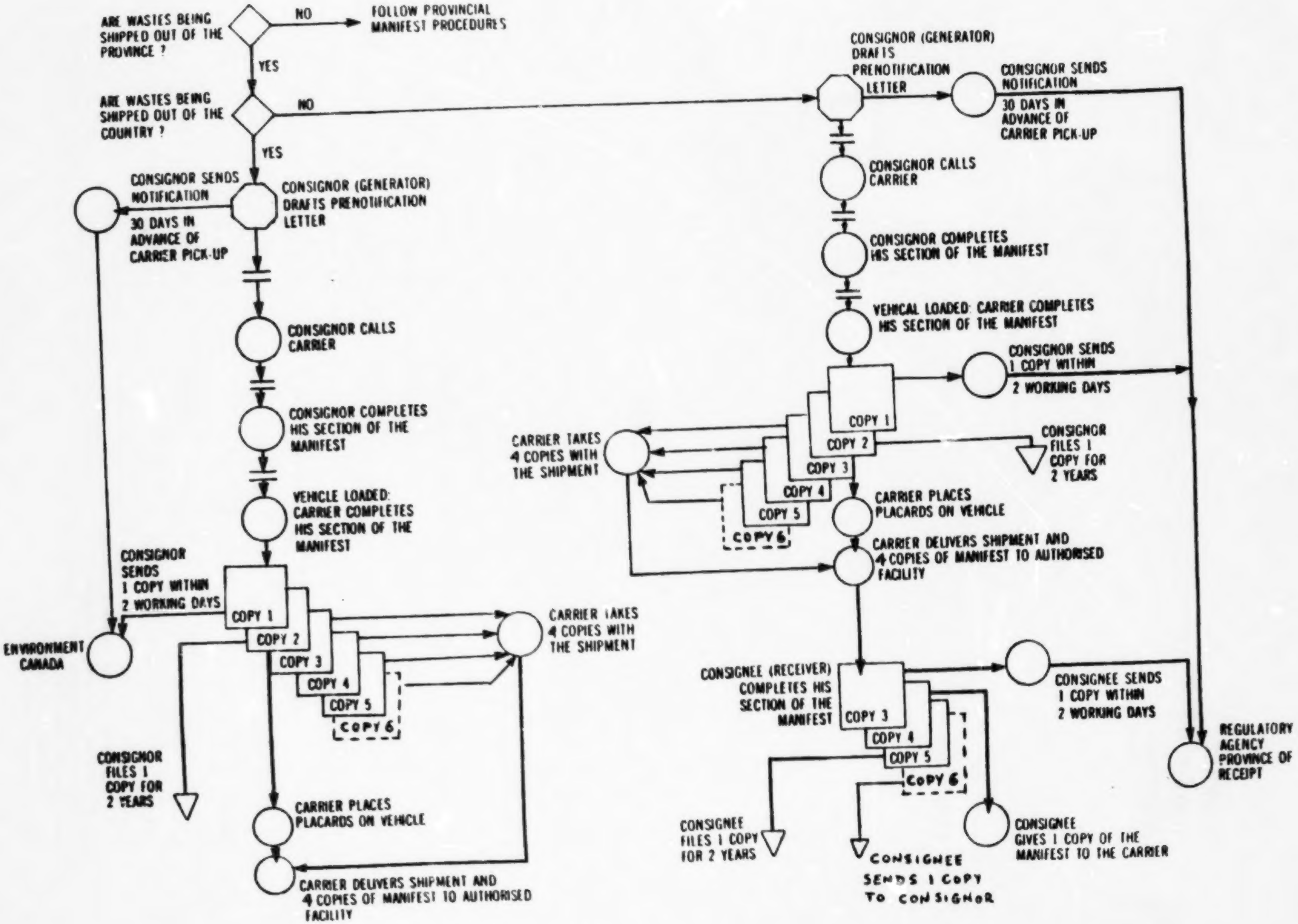
As far as spills are concerned, hazardous wastes will be treated as any dangerous good in transit.

JM/lc

13-2-81

Figure 1

## PROPOSED DANGEROUS WASTES SHIPPING PROCEDURES


ARE WASTES BEING SHIPPED OUT OF THE PROVINCE ?
NO
FOLLOW PROVINCIAL MANIFEST PROCEDURES
YES
ARE WASTES BEING SHIPPED OUT OF THE COUNTRY ?
NO
YES
CONSIGNOR SENDS NOTIFICATION
30 DAYS IN ADVANCE OF CARRIER PICK-UP
CONSIGNOR (GENERATOR) DRAFTS PRENOTIFICATION LETTER
CONSIGNOR CALLS CARRIER
CONSIGNOR COMPLETES HIS SECTION OF THE MANIFEST
VEHICLE LOADED: CARRIER COMPLETES HIS SECTION OF THE MANIFEST
CONSIGNOR SENDS 1 COPY WITHIN 2 WORKING DAYS
COPY 1
COPY 2
COPY 3
COPY 4
COPY 5
COPY 6
ENVIRONMENT CANADA
CARRIER TAKES 4 COPIES WITH THE SHIPMENT
CONSIGNOR FILES 1 COPY FOR 2 YEARS
CARRIER PLACES PLACARDS ON VEHICLE
CARRIER DELIVERS SHIPMENT AND 4 COPIES OF MANIFEST TO AUTHORISED FACILITY
CONSIGNOR (GENERATOR) DRAFTS PRENOTIFICATION LETTER
CONSIGNOR SENDS NOTIFICATION
30 DAYS IN ADVANCE OF CARRIER PICK-UP
CONSIGNOR CALLS CARRIER
CONSIGNOR COMPLETES HIS SECTION OF THE MANIFEST
VEHICAL LOADED: CARRIER COMPLETES HIS SECTION OF THE MANIFEST
CONSIGNOR SENDS 1 COPY WITHIN 2 WORKING DAYS
COPY 1
COPY 2
COPY 3
COPY 4
COPY 5
COPY 6
CARRIER TAKES 4 COPIES WITH THE SHIPMENT
CONSIGNOR FILES 1 COPY FOR 2 YEARS
CARRIER PLACES PLACARDS ON VEHICLE
CARRIER DELIVERS SHIPMENT AND 4 COPIES OF MANIFEST TO AUTHORISED FACILITY
CONSIGNEE (RECEIVER) COMPLETES HIS SECTION OF THE MANIFEST
COPY 3
COPY 4
COPY 5
COPY 6
CONSIGNEE SENDS 1 COPY WITHIN 2 WORKING DAYS
REGULATORY AGENCY PROVINCE OF RECEIPT
CONSIGNEE FILES 1 COPY FOR 2 YEARS
CONSIGNEE SENDS 1 COPY TO CONSIGNOR
CONSIGNEE GIVES 1 COPY OF THE MANIFEST TO THE CARRIER

14/4/82

# Uniform
# Hazardous Waste
# Manifest

**Manifest Reference Number**

**Reference Number(s) of Other Manifest(s) Used**

## B Carrier

Waste Hauler Number

Company Name

Business Address

City | Prov.

Telephone

Veh./Trailer/Container Serial No.

Driver's Signature

## A Consignor

Provincial Registration No.

Company Name

Business Address | City | Prov.

Site Waste Shipped from

Special Handling/Emergency Instructions

## C Consignee

Provincial Approval No.

Company Name

Business Address

City | Prov.

Site Waste Received

| ✓ | | Shipping Name | Product I.D. Number | Hazard Class | Danger Group | Quantity Shipped | | | | | Packaging | | Rec'd as Shipped ✓ | | Identify any Shipment Discrepancy | Handling Code |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sol | Liq | | | | | Number | ✓ kg | lbs | ✓ l | gal | Number | Type Code | Yes | No | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

Transfer Waste to (Consignee's Name)

Business Address | City | Prov.

Waste Site

Name of Authorized Person | Telephone

Date Released Day Month Year | Authorized Signature

Handling Method, if other than on Reverse

Certification: *The Wastes described on this Manifest have been received.*

Name of Authorized Person

Telephone

Date Received Day Month Year

Authorized Signature

**Copy 1 Province of Consignee - Mailed by Consignor**
**Copy 2 Consignor - Retained by Consignor**
**Copy 3 Province of Consignee - Mailed by Consignee**
**Copy 4 Carrier - Retained by Carrier**
**Copy 5 Consignee - Retained by Consignee**
**Copy 6 Consignor - Mailed by Consignee**

# APPENDIX N
# REFERENCES

# APPENDIX N
# GENERAL REFERENCES ON LANDFILL CRITERIA FOR HAZARDOUS WASTE FACILITIES

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